Author:
Gordillo Bravo, Carolina C

Title:
Exploring the influence of tracking moving objects on declarative learning through video games

Author:
Gordillo Bravo, Carolina C

Title:
Exploring the influence of tracking moving objects on declarative learning through video games

Exploring the influence of tracking moving objects on declarative learning through video games

By Silvia Carolina Gordillo Bravo

A dissertation submitted to the University of Bristol in accordance with the requirements for award of the degree of Doctor in Philosophy in the Faculty of Social Sciences and Law.

School of Education

June, 2020

Word count: 64,012

Abstract

Action video games require players to monitor, track and respond to moving stimuli. Evidence suggests that playing video games can have a positive influence on cognition, learning and brain plasticity. Possible explanations for these effects may involve the levels of attention required to enable an accurate representation of moving elements. However, the key features of video games responsible for these effects have not been identified, and the mechanisms by which video games may produce higher levels of attention and learning are not completely understood.

This thesis reports on five experiments that attempt to explore whether declarative memory for semantic information associated with objects is enhanced when the objects are in motion and need to be tracked and acted upon – as part of an educational game – compared to when they remain stationary and acted upon. In every game, participants were required to identify and act on objects containing numbers, according to whether it was a prime number or not. Experiment 1 (N=20) explored the research question through a single game session and found that prime numbers learned under the motion condition (moving objects) were recognised faster compared to the control game, but not more accurately, suggesting a speed-accuracy trade-off. The extension of game play to five sessions in Experiment 2 (N=16) showed that duration of play had a stronger initial effect on learning in the motion condition than when the objects were static, but over all five sessions no statistically significant difference in learning could be established between conditions. Using an enhanced version of the game with more game-like features, Experiments 3 (N=19), 4 (N= 49) and 5 (N=51) found no difference in the recall of information learned through acting on moving or static objects. An element of social competition in the form of a 2-player mode was added to Experiment 5, which showed that, during game play, accuracy was significantly higher for information learned through tracking moving objects, suggesting a motivational effect that acted favourably in conjunction with the motion tracking feature of the game and provided faster recall.

Taken together, the findings of the present research suggest that acting on moving objects as part of video game play is not associated with better declarative memory for semantic information related to the object. An underpowered design, as a result of small sample sizes in the experiments, may be the reason for the lack of evidence to detect this effect. During game play, however, there was some evidence of higher levels of accuracy over trials for identifying stimuli compared with the static condition, suggesting enhanced levels of attention may have been deployed. These findings suggest that tracking may recruit more attentional resources to the stimuli during game play, which may impact performance for identifying stimuli during the game, but this did not produce measurable improvements in subsequent tests of declarative memory for stimuli.

Results are discussed in terms of the theoretical principles that supported the hypothesis of the effect of motion tracking on declarative memory, the limitations of the tasks designed, the epistemological constraints of conducting laboratory experiments for educational learning and recommendations for further exploration of the features of video games that may produce learning of educational value.

A mis padres,
Sylvia y Alberto

'There is hope in honest error,
none in the icy perfection of the mere stylist'

Charles Rennie Mackintosh, 1901

Acknowledgements

This work would have not been possible without the financial support of Conicyt Becas Chile, the Chilean programme of scholarships for doctoral training.

This project took 1,723 days of my life. During those many days, many people were involved and contributed to my research apprenticeship in different ways. To them all, I owe my deepest gratitude.

I would like to thank both my supervisors for their generosity with their knowledge, their strong encouragement and kind support. To Professor Paul Howard-Jones, who has been my teacher and my critical and caring mentor all these years. I have been privileged to work with him and learn so much from his research in the field of educational neuroscience. Thank you, for supervising my work and helping me develop not only as a researcher but also professionally and personally. I would also like to express my gratitude to Dr. Shelley McKeown-Jones, my second supervisor, for her always wise advice on doing research properly, survival skills for the writing stage, and for her always kind words of support.

I am also grateful of all the academics in the School of Education that I have worked with either as a TA or as an RA. This 'other' learning experience also contributed to my development as a researcher and as a tutor. Many thanks also to the administrative staff for their prompt response whenever I needed help, to the librarians for their helpful advice, and to the porters who were always so nice to me in the morning and kicked me out of the lab late at night when they need to lock the building.

To all the new friends and colleagues from all over the world that I have met during my studies, thank you for being so supportive and loving. I treasure with love all those moments of celebrations, lunch breaks, tips for the jammed photocopy, or the latest event in town… It has been a pleasure to meet such diverse and smart bunch of people. Also, to my lovely housemates Adri, Ed, Calum and Jakob who made my life so beautiful on the first two years of my PhD. Lots of conversations in the kitchen, good food and celebrations. Finally, I am also thankful of my Chilean gang – Paulina, Miguel, Eileen, Betza, Daniela, Igor, plus a Mexican addition, Dulce – for your precious friendship, optimism, deep conversations in Chilean Spanish, and permanent encouragement.

Finally, I am forever grateful of my caring and supportive family and friends in Chile, whom I have not seen in many years now. Thanks for the long-distance support, calls, cards, visits and presents. Especially to my elderly parents whom I miss so much and I long to see and hug again. Their love, care and permanent encouragement has kept me going and this work is dedicated to them. And to my new family in the UK, my adored partner and future husband – James – whom I met as a fellow doctoral student and has changed completely my experience of living and studying in Bristol. His permanent support, belief in me, love, care, coffee and proofreading were undoubtedly a luxurious source of support, especially in the final weeks. Thanks, to him and also to his family who has welcomed me from the very first day as one of their own.

In the midst of the world pandemic and after two and a half months of lockdown, I feel also grateful that despite the worries and the uncertainty we are living in, I was able to finish this thesis in relatively good physical health and with my loved ones still around.

Author’s declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's *Regulations and Code of Practice for Research Degree Programmes* and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others is indicated as such. Any views expressed in the dissertation are those of the author.

SIGNED: ....[redacted]................. DATE: 8 June, 2020

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ACC	Anterior cingulate cortex
AIPS	Anterior intraparietal sulcus
BOLD	Blood-oxygenated level dependent
CH	Correct hit
CM	Correct miss
EEG	Electroencephalography
FEF	Frontal eyelid field
FINST	Fingers of Instantiation
fMRI	Functional Magnetic Resonance Imaging
IFG	Inferior frontal gyrus
IH	Incorrect hit
IM	Incorrect miss
K-S	Kolmorogov-Smirnov
MCQ	Multiple-choice questionnaire
MIT	Multiple Identity Tracking
MOT	Multiple Object Tracking
MT+	Human motion area
NR	No response
PE	Prediction error
PIPS	Posterior intraparietal sulcus
rPFC	right prefrontal cortex
RT	Response time
SAT	Sustained attention task
SPL	Superior temporal lobule
WM	Working memory

Chapter 1 Introduction

Video games have occupied an increasing place in the lives of children and adults in Western cultures. Surveys indicate that 75% of American homes have at least one person who plays video games three or more hours per week and that the average age of video game players is 33 years (ESA, 2019). In the UK, 21.7 million people between the ages of 6-64 play video games, equivalent to 46% of the population within that age range (GameTrack (IFSE/Ipsos Connect), 2017). Although characteristics of players vary widely and there is not considered to be any typical video game-playing type (GameTrack (IFSE/Ipsos Connect), 2017), it is fast-paced games, including first- and third-person shooter and action games, that have been the most popular (ESA, 2016).

This popularity of video game play may be attributed to the high levels of engagement they trigger in their players. A simple observation of people playing games on computers, consoles or portable devices confirms the enthusiasm and attentiveness they put into the task. This engagement has been initially ascribed to certain features of video games thought to generate higher levels of arousal and attentiveness, such as challenge, fantasy and curiosity (Malone, 1981). The advent of more sophisticated games and technological advances has allowed for other features such as competition, uncertainty and action**,** which may additionally contribute to player engagement (Kirriemuir & McFarlane, 2004). Regardless of the impressive evolution in the platforms used for playing over the years, there seem to be common elements present in those video games that captivate their players.

Action video games have been extensively researched for their influence on cognition and attributed to a myriad of cognitive benefits with potential for enhancing educational learning. These games feature fast-moving elements that quickly appear and disappear from a visual field, requiring players to monitor, track and respond to moving stimuli (by firing, throwing, aiming at, hiding, jumping, etc.). It has been suggested that when players need to monitor several cues or track elements in motion on the screen before deciding on the correct response, higher levels of attention are required to enable a more accurate representation of the elements being shown (Boot et al., 2008; Dye et al., 2009a; Dye & Bavelier, 2010). From a cognitive psychology perspective, representations that grow in accuracy are also better consolidated in the declarative memory system, making them more responsive to retrieval when required to associate another representation (Eichenbaum, 2004). Declarative memory is one of the forms of learning that occur in educational contexts. Hence, a possible association between the feature of motion (represented through moving objects in video games) and learning may arise because action video game play demands higher attentional resources and with that more cognitive resources that may lead to learning the material being played (Bavelier et al., 2012a).

The engagement offered by action video games, added to their potential benefits for some aspects of cognition, has resulted in the industry of edutainment sparing no effort in producing video games for learning, also known as edu-games, that contain the features encountered in their entertainment counterpart. This endeavour has not been free of challenges, and educational video games have faced the difficulty of adequately balancing and integrating both entertainment and learning material in order to engage players into play and learn without perceiving game play activity as a learning task. One of the best known edu-games is MathBlaster (Davidson, 1983), both an online and console game, that includes fast-paced action and shooting elements to solve maths problems. A more modern online platform – *Mangahigh* (mangahigh.com) – offers a variety of video games designed to learn arithmetic and algebra that include action elements, such as flying penguins to add or subtract or shooting at incoming numbers to complete number bonds, emulating the action features of well-known games such as *Angry Birds* and *Space Invaders*. The action element present in the most popular entertainment video games has been regarded as one of the key features to keep players engaged in the educational versions of gaming. The potential of first-person shooter games for learning math problems has been even endorsed by the former British Education Secretary, Michael Gove, in a speech about how to harness technology in the classroom delivered at the Royal Society (Gove, 2011).

Evidence around the effectiveness of these games for educational learning, however, is mixed and sparse. Initially, games for learning did not achieve success mainly because they failed to offer embedded educational content in game patterns that resembled real games (Kirriemuir & McFarlane, 2004). Game developers and researchers have labelled these games as 'chocolate-covered broccoli' to illustrate the weak relationship between games and learning. In time, several reviews (Boyle et al., 2016; Connolly et al., 2012; Hainey et al., 2016; Wouters et al., 2013) have revealed the need for more empirical evidence on the effectiveness of different genres of games in the learning of a range of skills and knowledge. In 2012, Connolly and colleagues (2012) confirmed the wide diversity in the focus, methodology, theoretical underpinnings and outcomes for research in video games, making it difficult to establish solid conclusions on the relationship between video games and learning. Later, Boyle et al. (2016) expanded Connolly and colleagues' database to conclude that although some progress has been made in understanding how specific video game features engage players in learning, research in this area was still fragmented and needed more evidence. In terms of games for learning, these have been found to be more effective than regular instruction in some instances, but paradoxically they are often not motivating enough for players to keep playing them (Wouters et al., 2013).

The absence of firm evidence to claim the effects of video games for learning might be attributed to the lack of basic understanding of how key features of games work in relation to engagement and learning (Mayer, 2015, 2019), which may have prevented the development of games optimally designed for learning. For example, research on the mechanisms of action involved in games and its influence on attentional processes has been deemed necessary for understanding how action video game play might influence learning before establishing the potential of action video gaming for educational application (Bavelier, 2012). As the game-based learning sector diversifies at the pace of technology, rapidly generating new immersive environments with virtual and augmented reality gadgets, it becomes relevant for the research area to contribute bona fide knowledge of how the orchestration of material and mental mechanisms operate to produce learning with educational video games. Mayer (2015) addresses the need to generate evidence on learning through video games by proposing three areas or question types that need to be researched. The first is the value-added question which investigates the features of games that can improve academic learning and it is oriented to determining whether the adding or modifying a specific feature within games may have an incidence in learning performance. The second question relates to the cognitive consequences that playing off-the-shelf video games might have on academic learning, considering that such games were never intended for learning. The third question refers to the comparison of media in terms of learning, i.e. is a game better for learning than traditional media. All three areas represent a guideline to advance the field in a more structured way and establish more solid links to theory and game design for learning, moving beyond broad perspectives and descriptions of game playing.

Addressing gaps in current understanding, the present research focuses on the value added by action video games and examines evidence for enhanced cognitive skills. Specifically, the present research aims to investigate whether the action of visually tracking objects in motion might be involved in enhanced learning via the deployment of more cognitive resources. Different fields related to the cognitive sciences have supported the connection between motion tracking and learning. Evolutionary perspectives suggest that different species seem to share an object tracking system which developed for survival purposes and has allowed for the faster identification of moving targets compared with static ones (Agrillo et al., 2014). Similarly, acting upon what is being tracked, which is what regularly occurs in a video game by catching or shooting at, resonates with the conceptualisations of embodied cognition that incorporate and emphasize sensory and motor functions as part of the human cognitive processing (Wilson 2002). Developments in neuroscience have been able to show how neuromodulators related to enhanced encoding of declarative memories trigger when there is a change from monitoring for cues to a cue-directed action (Howe et al., 2013), which is another gesture that mirrors video game play. Finally, extensive research in visual cognition using paradigms of multiple-object tracking (MOT) suggests additional cognitive resources are allocated to visually track objects in motion (Cohen et al., 2011; Oksama & Hyönä, 2004; Pylyshyn & Storm, 1988), and explains how interrelated attentional processes and working memory act when the task of keeping track of moving objects occurs (Hu et al., 2018; Li et al., 2019; Oksama & Hyönä, 2004, 2008; Wei et al., 2017). Following the general evidence for video games and their potential for cognition through the increase of attentional resources and the evidence for visual tracking that makes recourse to attention and working memory processes, it can be hypothesised that the tracking of a moving stimulus (in an educational video game) and responding to it (as part of the game play) may improve the learning for semantic information related to that stimulus. Within the taxonomy of memory systems, this semantic information corresponds with declarative memory, which is a type of learning that takes place in educational contexts and its learning is relevant to constructing more learning.

Theoretically, this research revolves around three points of intersection in the relationship between video games and learning: a) evidence of the relationship between cognitive processes, such as attention and working memory, and their influence on declarative memory formation; b) evidence on the positive effects of video game play on engagement and attentional deployment, which potentially lead to declarative learning; and c) the unexplored relationship between video game play and declarative memory formation which in this research is based on the theoretical principles behind visual attentive tracking of objects in motion (Scholl, 2009; Wei et al., 2018) and cue-directed action in goal-oriented tasks and the cholinergic influence it exerts on attentional processes and encoding of declarative memory (Howe et al., 2013; Parikh & Sarter, 2008) (Figure 1.1). The first two points of intersection (points a and b) are well evidenced in the literature and are the foundation to experimentally explore point c) as a plausible hypothesis to test in this research project.

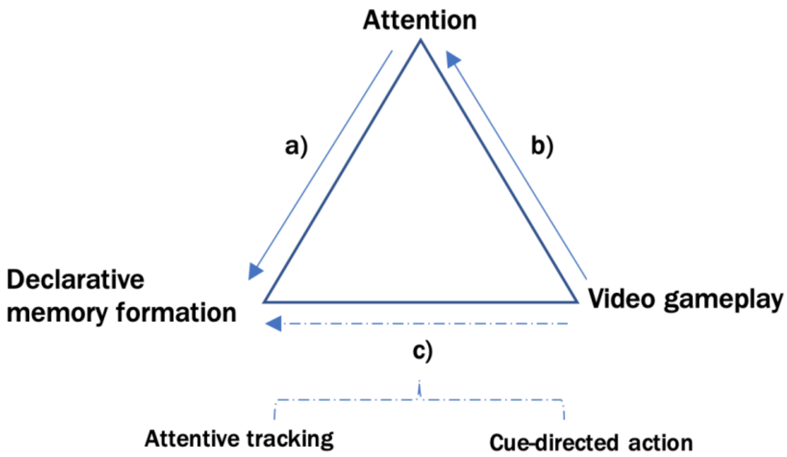


Figure 1.1. Points of intersection showing the relationships between video game play and learning. Point a) shows the relationship between attention which, in conjunction with working memory, influences declarative memory formation; point b) refers to the relationship between video game play and enhanced levels of engagement and attentional processes that may eventually lead to declarative learning; and point c) reflects the unestablished relationship between video game play and declarative memory formation based on the features of attentive tracking and cue-directed action.

By incorporating the feature of tracking and responding to motion – commonly seen in action video games – to a learning computer game-like task and investigating its effect on the recall of information contained in the moving stimulus, this project proposes an original approach that will provide insight into one of the common features of video games to understand the processes by which their known cognitive effects come about. It is also an attempt to identify underlying processes of game-based learning that can inform design principles for the development of educational technology involving games. The relevance of this study lies in the growing interest in the potential of computer games for education and the little evidence there is from research on the understanding of the features that may influence declarative learning through video game-based learning.

The present research is situated within the field of educational neuroscience – in the sense that cognitive processes will be explored from a brain-mind perspective to inform educational practice, while considering how educational learning occurs as a societal construct. The need to bridge the gap between the cognitive sciences and education to get a more complete understanding of human learning has encouraged the emergence of this field, one which has not been free of scepticism and controversy. Yet it is important to make inroads in the field through experimental research on how human learning can be aided by game-based technology. For the specific aims of this research, an educational neuroscience perspective brings together understandings from cognitive psychology and neuroscience to understand learning occurring with certain stimuli, but it also seeks understandings from an educational perspective which can be used in combination to increase the ecological validity of the experimental tasks.

This thesis is structured in seven chapters that articulate the context, theoretical underpinnings, design, data and results of the studies conducted in this research project. **Chapter 1** introduces the reader into the topic of the thesis and delineates the rationale for the research, providing a brief context for the problem and the way to address it. It also outlines the structure of the thesis to guide the reader through the different sections. **Chapter 2** reviews learning from both a cognitive and an educational perspective by introducing the types of learnings that have been described upon such perspectives. Similarly, the chapter addresses the understandings of memory and attention that are used in this research together with the learning associated with video game play that has been researched. **Chapter 3** explores the theoretical foundations that support the relationship between visual tracking and the recourse of cognitive mechanisms involved in learning. Evidence ranges from evolutionary perspectives to research paradigms emerged from visual cognition studies, touching also on evidence provided by the research program of embodied cognition, insights from cognitive neuroscience and research in action video games. **Chapter 4** contains an explanation of the philosophical issues related to the concept of learning in the field of educational neuroscience. Additionally, epistemological matters addressed in this chapter elucidate the need for laboratory studies to explain a real-world phenomenon. The second part of this chapter is dedicated to the general outline the methods used to collect and analyse data. It also explains in detail how the two game-like tasks for this research were designed. **Chapters 5 and 6** present the results of the experiments. Each chapter represents an experimental phase with specific aims, tasks and materials. Phase 1 provides the results, analyses and discussion for Experiments 1 and 2 using Game-Like Task 1, while Phase 2 presents the results for Experiments 3, 4 and 5 using Game-Like Task 2. Finally, **Chapter 7** leads the reader to a final general discussion of the evidence obtained through these experiments. A section for Conclusions will put the results of this research into a wider perspective that includes recommendations for further research.

Chapter 2 Perspectives on learning

Learning is at the basis of the nature of humanity and is its driving force (Jarvis & Parker, 2007), and yet it is one of the concepts that posits the most problematic delineations. Defined in basic terms, learning is characterised as a capacity to change a structure or behaviour by means of processes which are not only biological or developmental, but also social (Illeris, 2012). However, most theorists would argue about the difficulty in defining learning further, mainly because of the different ontological and epistemological traditions involved in its conceptualisation (Säljö, 2009). The disciplinary boundaries that have approached the understanding of learning have enriched but also restricted its inquiry (Jarvis & Parker, 2007) and have created artificial, but inevitable divides in its conceptualisation as a human activity. Although it is impossible to agree on one universally accepted established definition of learning, most common conceptualisations of learning refer to the interplay of change, processes, environment and time (Illeris, 2007).

The concept of learning has been traditionally associated with educational contexts. A long-standing traditional view of education has approached the problem of learning from a teaching perspective. The role of pedagogy is central to conceptualisations of educational learning, as this process is attributed to the instructional action of another (Schunk, 2012). A social outlook to education and learning has been mainly instilled by Vygotsky's ideas of learning with others and how a more knowledgeable other could lead a child into achieving learning. Over time, approaches to education have gradually started measuring learning as an indicator of teaching success. Psychological sciences have been involved in the educational field with a longstanding tradition of psychometrics, which may have granted a more asocial and cognitive perspective to be associated with formal educational settings (Heyes, 2012). Nevertheless, while a more social understanding of learning has lost ground to more cognitive traditions based on psychology, the field of cognitive neuroscience has provided increasing evidence on the underlying biological processes involved in learning. This has not only enriched and widened the understandings of learning with state-of-the-art insights from the biological and psychological sciences, but also expanded the notion of interdisciplinarity among fields, especially through the emergence of educational neuroscience.

Situated at the interface of two apparently distant fields, this doctoral research takes an educational neuroscience perspective by seeking to draw on neurocognitive mechanisms to study learning in tasks that reflect potential aspects of educational contexts. Formal educational institutions seek to foster learning, but their understanding of it is permeated by many influencing factors, such as societal drives and government policies as well as learners' motivations and classroom acceptable practices that need to be considered and ideally matched in order to achieve learning. Furthermore, with the inclusion of digital technologies in education, another dimension of the understanding of educational learning has been added. Therefore, research evidence on the underlying neural mechanisms of learning will be used in conjunction with educational understanding of learning, thereby informing the design of suitable experimental tasks that explore underlying processes while preserving ecological validity. This will enable the understanding of how playing an action computer game-like task can influence declarative learning, a type of learning that is of key interest within educational contexts.

This chapter explains the processes and actions involved in the concept of learning when it is understood from both a cognitive neuroscience and educational perspective. Attention, the ability to select information from the environment or from our memory (Raz & Buhle, 2006), is taken as the starting point of learning from a science perspective, as it is considered the gateway for all learning. The interplay between attention and working memory (defined as the capacity to sustain information temporarily in a goal-directed task), will also be reviewed in a first section of the chapter as they both are essential mechanisms of our cognitive capacity (Fougnie, 2008). While attention and working memory act as cognitive resources for learning, a second section will address the different interacting systems in the brain whereby learning occurs, including the system for memorising concepts or specific moments, as well as one for learning procedures via practice or reinforcing learning via rewards. In all of these systems, memory is the common element that makes learning in the brain possible, sometimes with different categorisations of memory type depending on the type of learning associated with it. A third section will address how these learning processes manifest in formal educational contexts whose social nature contrasts with the asocial nature of learning studied from a cognitive perspective but which may be underpinned by the same neurocognitive processes. Finally, a section that addresses how video game play has influenced cognitive mechanisms such as attention and working memory will be reviewed to understand their potential for education. The inclusion of neuroscientific evidence in this review is intended to complement the psychological explanations and to achieve a deeper understanding of the cognitive mechanisms of learning through motion tracking which in the present study are reseached through a behavioural paradigm. Situating this research under an educational neuroscience paradigm contributes to bridging the disciplines associated with cognitive processes that may inform educational learning.

2.1 Attention and the brain

Attention is the allocation of mental resources, which is key for enabling learning in the brain (Amso & Scerif, 2015; Franz, 2012). In a world full of competing stimuli, the brain needs a system to 'filter' the amount of information in order to intake parts of it at any one time and make sense of it. Posner et al. (1980) first described a model of three separate attentional systems, namely alerting, orienting, and executive attention. While *alerting* involves the mechanisms of arousal taking place when an external and unexpected cue is elicited to become ready for action, *orienting* involves a shift of attention to select information from the environment, and the *executive* is the process by which the conflicting inputs problem is resolved and a goal-relevant action is selected. Each one of the described attentional systems is supported by different brain networks which interact closely together with an interdependence that is not clear (Raz & Buhle, 2006). Hence, depending on the nature of the stimuli, the brain makes recourse to these different attentional systems which all share the characteristic of being limited, making the brain trigger a process that allows us to select and act over one stimulus while filtering the others (Amso & Scerif, 2015).

Another mechanism acting in coordination with the attentional systems is working memory, which is a mechanism needed for maintaining information in conscious awareness in a temporary manner in order to complete a task (Baddeley & Hitch, 1974; Baddeley & Logie, 1999). Like attention, working memory is considered a non-unitary system that involves other cognitive processes for encoding, storing and manipulating information and has been organised as a model with multiple components for independent storage of verbal, spatial and visual information (Baddeley & Logie, 1999). Alternative models (called state-based models) have emerged to the one multi-component model suggested by Baddeley and Hitch (1974). They have proposed that the allocation of attention to internal representations of semantic, sensory or motor nature acts as the underlying process for the brief retention of information in working memory (D'Esposito & Postle, 2015). The two categories that encompass the state-based models of working memory are based on the type of stimuli involved. Hence, for a semantic type of stimuli (words, numbers, letters) activated long-term memory (LTM) models have been proposed, while for more perceptual stimuli (colours, auditory timbres, visual orientations) sensorimotor recruitment models have been proposed (D'Esposito & Postle, 2015). Regardless of the type of stimuli attended, all these models are based on the relationship between attention and working memory highlighting the importance of attentional prioritization in the actions of working memory.

The close relationship between attention and working memory has long been theorised and discussed but its nature is still a matter of debate (Fougnie, 2008; Van der Stigchel & Olivers, 2019). While attention acts as a mechanism for selecting information, working memory provides the mechanism for retaining such information temporarily. Due to the non-unitary nature of both attention and working memory mechanisms, theorists have argued that this relationship depends on which attentional system and working memory processes are involved (Fougnie, 2008). Hence, it has been argued that the interaction between attention and working memory is intimate during the processes of encoding and manipulation of information. Conversely, attention seems to have a more limited role in the maintenance of information (Fougnie, 2008), although working memory depends on the ability to direct attention away from distracting external sources, which implies a kind of participation of attention in the maintenance of information. For Oberauer (2019), the understanding of the interaction between these two mechanisms lies in a twofold conceptualisation of attention: as a limited mental resource or as a process for selecting information. Each of these characterisations suggests a different role for attention when theorising about working memory. Considering attention as a resource establishes its role for the limited capacity of working memory, whereas when attention bears the role of a selective information processing mechanism, the relevant question is how the different forms of attention interact with working memory (Oberauer, 2019). While Oberauer supports the idea that attention exerts a role of control of working memory rather than being a requirement for its maintenance, Van der Stigchel and Olivers (2019) argue that attention acts as an emergent property for maintaining only relevant information to the task. At a brain level, the processes of attention and working memory are represented by an overlapping of neural mechanisms and brain areas, especially the frontal eyelid field (FEF) section of the prefrontal cortex which overlaps in both functions (Bahmani et al., 2019). This area has also been identified as highly activated under the orienting attentional system proposed by Posner and colleagues (1980) which is the system that triggers when there is a shift of attention in order to select information.

Regardless of how the interaction of attention and working memory mechanisms take place, an essential outcome for learning is that the information that is processed in short-term memory (or working memory) can transition to a longer-term storage to be able to be used in further situations. In behavioural terms, it has been noted that, through constant retrieval from long-term memory and practice, retrieval processes become automatic, i.e. they no longer require effort to be performed (Ashby & Crossley, 2012). Although automaticity seems to be a self-explanatory term, its use has been mostly restricted to the type of memory of procedural nature, non-declarative memory, without a complete agreement on its meaning (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Among the different criteria used to establish automaticity, extended practice has occupied a central role. This one, however, does not seem a sufficient condition and other criteria have been proposed, involving the level of unconsciousness in the retrieval (Moors & De Houwer, 2006), the efficiency in the performance demonstrated by the ability to successfully perform the task while engaged in another task, and the difficulty to modify the behaviour once it is learned (Shiffrin & Schneider, 1977). These different criteria proposed for determining when a behaviour becomes automatic have failed to account for a single behaviour that can comply with all of them in order to be classified as fully automatic (Moors & De Houwer, 2006). Furthermore, because most criteria for determining the automaticity of a behaviour were developed before the notion of multiple memory systems, it is suggested that most frameworks lead to a misclassification of behaviours (Ashby & Crossley, 2012). This leads to the issue of how to distinguish when a behaviour becomes automatic based on its independence from the memory system that mediated its learning originally (Ibid).

In the present research, the concept of automaticity is applied to declarative learning as in the development of fluent recall through overlearning. Tasks, including those involving declarative memory, initially require more intensive levels of attention until, through reiterative practice, they become automatic, i.e. they can be performed rapidly and with minimal effort. This, in turn, frees up the mental resources of attention and working memory which can be then allocated to either selecting or discriminating newer information. Automaticity depends on a number of factors, including the extent of the information, the depth and type of processing, the level of practice or exposure to a situation, and individual differences, which leads to degrees of such process. A common example of automaticity in procedural knowledge is driving because it is a gradual mastering of a skill that initially required maximum levels of attention centred in one single activity. With practice, driving becomes an automatic process and, because of this automaticity, it frees up cognitive resources so that it is possible to do other things while driving, like listening to music or talking to a passenger, meeting the efficiency criteria. However, the concept of automaticity does not normally refer to declarative knowledge because this type of knowledge involves more conscious retrieval and, as such, it would not fit one of the criteria established for automaticity previously mentioned. One example of declarative learning that appears as automatic refers to fluency for mathematical facts which is the automatic recall of basic math knowledge such as tables of multiplication without conscious effort (Logan, 1988). Through instruction, practice and feedback, this declarative knowledge becomes effortless to recall and has been deemed essential for mathematical achievement (Stickney et al., 2012).

2.2 Learning, memory and the brain

Learning in the brain occurs in different ways that are classified into different types that involve specialised brain areas. A learning algorithm defines the way learning occurs in each of the types of learning, instead of using the goals of learning as a basis (i.e. whether learning is motor or sensory). Theories of computational learning have distinguised three major learning paradigms: supervised learning which is error-based learning; reinforcement learning, which follows a reinforcement signal through scalar reward; and unsupervised learning, which does involve a teaching signal (Doya, 1999).

2.2.1 Supervised learning

Learning implies monitoring of some kind and realising when errors are made. Input captured by the brain shapes its functional organisation, making it better and adapting its properties for the individual (Knudsen, 1994). Supervised learning is one way in which experience shapes the brain networks and is considered an error-based type of learning (Knudsen, 1994); for example, it is as if we have somebody telling the brain what is wrong and what is right in search of accuracy of performance. Sensorimotor learning is usually described under a supervised learning paradigm (Wolpert et al., 2011).

The key brain area involved in this type of learning is the cerebellum**,** which acts as a control between the input from the environment and what is being performed as an output. For a long time, the cerebellum was thought to play a role only in movement together with the basal ganglia and the cortex (Koziol et al., 2014). The study of neural networks has contributed to the notion that learning always involves the motor and sensory areas of the cortex (Stein, 2007). However, despite not really knowing how its contribution takes place, today it is thought that the cerebellum also supports the development of cognitive processes (Koziol et al., 2014). This is nonetheless another great step into considering the brain as an ensemble rather than a divided assembly of regions and abilities (Fair et al., 2009).

The involvement of supervised learning in the development of sensorimotor networks is related to complex motor processes, such as extreme abilities displayed in sports or more daily motor learning with new object manipulation or the refinement of existing skills (Wolpert et al., 2011). Playing action video games also has an impact on sensorimotor learning as demonstrated by a study on gamers who outperformed non-gamers in vision-hand coordination in a manual tracking task (Gozli et al., 2014). Using a tailored version of a tracking task, participants had to track with a mouse a target object moving in different directions and at different speeds in two different formats for the waveform, a repeated pattern and a changing waveform in every trial. Although regular players were better than non-players when the pattern was repeated, there was no difference between the groups when the pattern changed in every trial, showing that it was the training and not the previous gaming experience solely that affected the accuracy of the movements. This better learning was possibly due to the enhanced ability of gamers to learn novel sensorimotor patterns as it was more developed by their previous gaming experience, ruling out the idea that gamers' success could be attributed to enhanced sensorimotor control (Ibid).

Supervised learning, or error learning, is important for the development of some key skills in educational contexts, especially in the initial years that involve sensorimotor tasks, such as holding a pencil and producing intended patterns on a piece of paper. It is, however, not involved with declarative memory formation or the type of learning of educational value.

2.2.2 Reinforcement learning

Learning based in error signalling – supervised learning – will eventually reduce the average error to the minimum and when this occurs, the mechanism to systematically further improve performance will disappear (Wolpert et al., 2011). The brain needs then a system to make decisions from the input received and compare it to information already stored. This is reinforcement learning and it portrays the interaction between an individual and their environment in the acquisition of goal-directed behaviour (Barto, 1995; Sutton & Barto, 1998). This type of learning is grounded in the learning by trial-and-error proposed by behavioural psychologists, and it is the type of learning that allows us to create a map from experienced situations in order to take action for maximising reinforcement or reward (Sutton, 1992).

The need to solve a conflict of information when there is important information about a situation leads to the calculation of a prediction error (PE) after every action. This occurs when there is a disagreement between what is expected as a reward and what is actually received. For example, if the outcome exceeds the expectations, there is an adjustment to the next predictions based on this ratio. Therefore, a higher prediction error implies a ‘happy surprise’ (Howard-Jones et al., 2011) and a higher likelihood to repeat the action. If the outcome is below the expectation, the prediction error rate readjusts again. It is natural that individuals look for scenarios where higher gains may be obtained based on what has been previously experienced.

The basal ganglia are the brain structures that mediate this type of learning (Doya, 1999). They are a system of subcortical structures located in the hindbrain and midbrain and the striatum is its main structure associated to the release of dopamine, a neurotransmitter involved in the response to reward and its anticipation (Schultz et al., 1997) that plays a role in the modulation of pleasurable activities, like playing computer games (Koepp et al., 1998). Dopamine released from the midbrain and projected to the striatum reshapes the representation of the situation in the cortex based on the prediction error ratio.

The relationship between the neuromodulator dopamine and the rewards involved in reinforcement learning seems to operate in relation to the reward schedule over time. While the activation of dopamine increases at the same rate for the best reward possible in every independent situation, revealing that the size of the reward is contextual (Knutson et al., 2001; Nieuwenhuis et al., 2005), it is with unexpected or surprise outcomes (regardless of whether they are positive or negative) that major spikes of dopamine occur, making individuals more inclined to continue on task (Berridge & Robinson, 1998). This uncertainty in the reward schedule has been also been found relevant for estimating the accuracy of predictions in a study in primates (Fiorillo et al., 2003). The effects of the relationship between reinforcement learning and reward can be observed in the preference for chance-based games that lead people to loose more than to win (Shizgal & Arvanitogiannis, 2003). Video game players show behaviours related to unexpected scheduling of rewards in a reinforcement learning task that becomes pleasurable and engaging despite the irregularities of the gain. Similarly, video games are designed in stages that progress from simply engaging reward obtention to a more complex system that requires higher levels of mastering in order to maintain engagement levels.

The relationship of rewards and declarative learning has been researched in terms of the effects of rewards in memory but with some mixed results that emphasise the need for a deeper understanding of such association (Howard-Jones, et al., 2016; Mason et al., 2017). Loftus (1972) found that pictures with a higher value assigned for correctly recognising them in a later test were more remembered, but more importantly was that individuals fixated more on such pictures during the encoding phase, implying a higher display of attention to the reward-associated images. However, Nilsson (1987) found that reward offered at different stages or simply not offered made no difference in recall and recognition tasks, which contradicts the subjective reports of individuals indicating that rewards had an influence on the effort they put into the task. Hence, it seems that it is the attentional process rather than the reward itself that can be associated with enhanced memory encoding and thus associated with a declarative type of learning. This evidence is relevant for the design of the experimental game-like task used in the present research intended to focus on a specific feature (motion) while reducing other typical features of games, such as a complex system of rewards.

Neuroscientific studies have furthered the understanding of the relationship between reward and declarative memory formation. Projections of dopamine in the midbrain interact with the hippocampus to help memory become units of motivational significance and thus become a representation that can guide behaviour later (Shohamy & Adcock, 2010). An fMRI study (Adcock et al., 2006) identified a neural system based on anticipated reward that endorses memory formation before learning takes place in adults who had to remember visual scenes each with high or low monetary rewards. The activation of the hippocampus and the ventral tegmental area was correlated with their enhanced LTM for the following scene to be remembered, showing evidence for reward-related brain activation before the encoding takes place which can predict the formation of declarative memory.

2.2.3 Unsupervised learning

Another type of learning can be the one that is unsupervised, as in 'learning without a teacher'. This is the learning that occurs when we categorise in our brain even without any guiding feedback (Dayan, 1999). It is the learning that silently takes place through the enormous flow of sensory information into the cortex that does not necessarily entail any associated punishment or rewards. In this learning paradigm, an individual will adapt their behaviour based on the observation of the environment without explicit signals associating certain observations with desired responses (as in supervised learning) (Oja, 2002). It is thought that this type of learning could generate maps or patterns in the brain built upon previous and accumulated experience (Barlow, 1989). The outcome of this learning consists of a new explanation of the observed data which improves the future decisions based on this new understanding (Oja, 2002).

This type of learning is usually implicit and largely unconscious. However, it can require conscious attention to initate the flow of information into the cortex (Raizada & Grossberg, 2003).

This process guides the basic mechanism of sensory adaptation; for example, the visual pathway (Barlow, 1989) which is required to constantly adapt to the surrounding environment. Folia and Petterson (2014) conducted an fMRI study on the implicit acquisition of an artificial grammar set. For the acquisition phase, participants were presented with artificial grammar sequences that they were told to retype for 20-40 minutes per day (for 5 days) without receiving feedback. During the grammaticality classification task after the intervention, subjects showed greater activation in the basal ganglia – which is related to implicit learning – and deactivation of the medial temporal lobe, associated with declarative memory, a type of learning that is explicit. This suggests the procedural and implicit nature of preference classification in unsupervised learning. Although these two brain regions identified with two distinct memory systems, their activation does not always occur in opposition and they have been shown to interact in a competitive fashion as well as in a non-competitive and more cooperative manner (Brown et al., 2012; Devan & White, 1999; Voermans et al., 2004). Although learning processes here are implicit and participants cannot explain how they know which the correct grammar is, they are able to explicitly declare the grammatical form (either correct or incorrect) following its learning. It is, however, a debatable point whether this explicit form of learning suggests a declarative element to the learning, but it clearly demonstrates the potential role of this type of learning in education.

Unsupervised learning is how we make meaning from the innumerable non-identical inputs from the environment and understand the world. As such, it is an approach that might also suit human-computer interaction to understand how computers adapt to the requirements of human use by just observing their behaviour (Oja, 2002). However, in educational contexts, the presentation of stimuli is intended to create declarative learning more directly, facilitating the sense making.

2.2.4 Memory systems

All different ways of brain learning share a common affordance in that they require the storage and retrieval of information, memory. This capacity has been described and organised in different models, most with a basic dual distinction: declarative and non-declarative memory (Squire, 1994). Such categorisation also follows the nature of the learning occurring in the brain. Non-declarative memory is mostly procedural and unconscious. Instead, declarative memory, explicit in nature and effortful, requires the display of mental resources involved in learning in order to retrieve information that can be 'declared' in the form of facts (semantic) or personal events (episodic) (Schacter & Tulving, 1994). This distinction in types of memory first emerged from evidence from brain-lesioned patients demonstrating an apparently different mechanism for both types of memories. These studies were also relevant to understand the independence of the memory systems and their association to different brain regions involved in each category. This illustrates that memory processes are not located in a specific area but are functionally distributed throughout brain networks. However, as explained earlier, learning processes in the brain might be termed non-declarative and can often occur alongside and interact with the formation of memories that might be described as declarative.

2.2.4.1 Non-declarative memory

Learning that cannot be declared corresponds to the unconscious recollection of the type of knowledge recalled through performance, e.g. the acquisition of skills (motor, perceptual and cognitive) and habits (Squire, 1994). It has also received the name of implicit memory (Schacter & Tulving, 1994). Skill learning and habit formation are learning that are stored under non-declarative memory and they are associated with reinforcement learning. Rodent studies have shown a recruitment of the basal ganglia and the dorsolateral striatum in non-declarative learning, which corresponds to the putamen and caudate areas in humans (Shohamy et al., 2008).

2.2.4.2 Declarative memory

This is the capacity of conscious recollection of inputs (experiences or facts) that can be declared. It is divided into two types of knowledge that can be acquired. First, semantic memory refers to facts, meanings, conceptual knowledge, such as many of the things we learn at school. Second, episodic memory refers to events of a personal nature which are consciously recollected in terms of their elements, time and location (Tulving, 2002). They have also a connection with the emotions as has been seen by studies supporting the role of the amygdala and the encoding of memories for emotional stimuli (Phelps, 2004).

The medial temporal lobe is the subcortical system – comprising among other structures the hippocampus – that has a key role in the formation, consolidation and retrieval of declarative memory (Cohen et al., 1997; Squire, 2004). The hippocampal function has been described mainly for declarative memory processes, particularly long-term memory. It stores memories for weeks and then it transfers them gradually to specific regions of the cortex (Kandel & Hawkins, 1992). The neurons in the hippocampus bear remarkable plasticity, such as the one required for learning (Kandel & Hawkins, 1992). The effects of long-term potentiation (Bliss & Lømo, 1973) in the neural pathways within the hippocampus are responsible for this. Plasticity is one of the most fundamental characteristics of the brain and refers to its capacity to change its structures and function upon experience (Kolb & Whishaw, 1998). A study by Maguire et al. (2000) showed that taxi drivers in London who had to learn a vast amount of information in order to prepare for an exam to obtain their licence had an increased volume in their hippocampus, in the area related to spatial learning, showing a correlation between the volume and the time spent on the job. This finding suggests that brain structures can be modified through experience. Similarly, other studies have emerged with findings on training-dependent plasticity in adults. The study revealed the capacity of modifying brain capacity upon intense environmental input, known as the activity of learning. It also represents an argument against the established notion of fixation in the adult brain structures, emphasising the role of the environment in learning and changing nature of the brain. Declarative memory is also of special interest for educational contexts as it resembles a part of what educational learning promotes and measures as an index of progress, the acquisition of knowledge. The denominations of declarative and non-declarative in relation to learning tend to restrict the concept of automaticity in learning. The visuospatial learning in the London taxi drivers, for example, is declarative in nature as they are able to name each of the streets in the map, but it becomes non-declarative as they cannot say how they learn them. When looking into learning in the brain, these taxonomies become restrictive for definining automaticity as seen earlier.

2.3 Learning in educational contexts

Societies have created educational institutions to structure our learning ability into a system with common orientations with further and more societal aims (Illeris, 2007). Although learning that occurs in such institutions is measured individually through a range of assessment types, it is often understood as being generated collectively, i.e. with the help of instruction and didactic material or via social interactions which offer a manifest social nature to educational learning. This social nature of learning adds a layer of complexity to our understanding of learning within educational contexts. This complexity in the concept of learning is the challenge research in educational neuroscience encounters and one which also emerges in the present research.

Evidence shows that social and asocial learning depend on the same cognitive mechanisms but they have traditionally been treated as separate phenomena, as if social learning occurs outside cognition (Heyes, 2012). Behaviours that arise from social learning are those that take place with the influence of others, and are understood to be supported by cognitive processes similar to those implied in asocial learning (learning individually) as, for example, they both make recourse to cognitive mechanisms to encode information in long-term memory, or that they both require attention to select relevant information from the environment. In formal educational contexts, learning with others implies the use of strategies such as learning by imitating others, using techniques to learn particular facts or events and developing procedures that with extensive practice become unconscious and allow further learning. These strategies used by learners incorporate higher order cognitive processes such as planning and evaluating in order to learn.

Although not under the same names, the types of learning described in the previous section can also be found in typical learning tasks within educational institutions. Similarly, memory is the central element to all types of learning observed in educational contexts, as it plays a central role in the acquisition of various cognitive abilities that are developed through education, such as reading, writing, problem-solving, among others (Byrnes, 2001). For example, the use of mind maps in which learners organise data to visualise patterns could represent the way in which the brain categorises information under unsupervised learning. Although in educational contexts most tasks are generally guided, these maps are not supposed to follow rules pre-determined by the teacher and yet learners establish categories for organising data into a format that makes sense to them. Among the sub-tasks involved in unsupervised learning, clustering and visualisation are those that can be associated with mind-mapping. Further tasks described under this type of learning include finding association rules and detecting anomalies within a pattern which also lead to the reduction and merging of categories into more global ones (Ghahramani, 2004). In educational contexts, however, this is a type of learning that is eventually modulated by pedagogical actions which intervene to support and guide the initial unsupervised organisation.

Despite not referring to it as such, educators need to support some forms of non-declarative learning, the type of learning thought to be elicited only through performance and that includes the development of sensorimotor skills. Motor skills associated with handwriting are developed in the early years of schooling and perfected throughout life. Young students' learning how to hold a pencil and apply the correct pressure to smoothly delineate lines and curves that will form the letters are part of this process (Schunk, 2012). Years of practice and rehearsal help them master this skill until it becomes automatised, i.e. unconscious and effortless. School subjects such as physical education are not the only ones responsible for developing sensorimotor skills, although they contribute hugely to this area. Music and art classes also help develop sensorimotor skills through learning how to play an instrument or by painting within the limits of a designed drawing or using different materials and techniques (Schunk, 2012).

Most educational learning targets a declarative type of learning, as it becomes the foundation for explicit demonstration in exams and basis for further learning. Certain themes are deemed necessary to learn as factual long-term memory items; for example, tables of multiplication, physics rules, chemistry notation, foreign language vocabulary or important dates, so they can be easily accessed when needed to be applied. Mathematical fluency is the name given to the ability to recall basic mathematical facts and it has been deemed critical for attainment in mathematics (National Mathematics Advisory Panel, 2008). Nevertheless, in educational contexts, the understanding of the involvement of the notion of memory in learning has somehow acquired a negative connotation due to the rote learning approach (learning by memory), now considered a type of learning with no purpose. An understanding of how factual elements involved in different processes are associated, for example how multiplication and addition are related, needs to occur at the same time so that a balance between rote and meaningful learning works better for educational learning (Byrnes, 2009).

Attention, as the process of allocation of mental resources to select, is the onset of all learning in so far as it must preceed other cognitive processes, such as working memory and storage in long term memory, with the potential to generate learning. Hence, if attention is impacted, a range of different types of learning can be influenced as well. This leads to the reasoned argument that if something is capable of triggering attentional systems more effectively in relation to the to-be-learned content, then it has the potential for enhanced learning. Today, it is widely accepted that video games trigger higher levels of engagement and motivation which might be seen as a behavioural demonstration of attentional deployment (Bavelier & Green, 2019). This may explain reported cognitive impacts on their users, and consequently they might be considered for their potential for educational learning (Bavelier et al., 2012). The next section reviews the evidence around video game play and its potential influence on attention and learning.

2.4 Effects of video games on attention and learning

Video games have been demonstrated as being a great influence on recruiting attentional systems. This has been attributed to their features which predominantly incite curiosity and involve challenge that fosters competition and action (Bavelier et al., 2011). The interplay of these elements within the game mechanics affects the levels of engagement of players who show higher levels of attention in order to complete the tasks required in the game. Additionally, due to the nature of game play and the characteristics involved in computer games, learning by trial-and-error and/or reinforcement learning can occur, which is intrinsically related to rewards and prediction error mechanisms in relation to the obtaining of rewards (Howard-Jones & Demetriou, 2009; Howard-Jones & Jay, 2016)

Research in video games has demonstrated that diverse areas of human learning can be influenced, particularly by action video game play. Some of the cognitive areas in which game play has been suggested to have an influence include spatial cognition (Greenfield, 2009; Spence & Feng, 2010), visual short-term memory (Boot et al., 2008), multitasking (Green & Bavelier, 2006), task-switching (Green et al., 2012), cognitive flexibility (Colzato et al., 2010) as well as some aspects of executive function (Chisholm & Kingstone, 2012; Colzato et al., 2010; Karle et al., 2010).

Attentional systems have also been shown to be positively influenced by intensive action video game playing, particularly in respect of visual attention (Dye et al., 2009a; Green & Bavelier, 2003; West et al., 2008). Due to the mechanics of action video games, players need to perform several tasks simultaneously, such as detecting incoming objects and tracking existing ones while avoiding the disruption of space and content rules. This does not only contribute to the development of enhanced visual attention in those who are avid video game players but can also help develop it in those who are not avid video game players after some training (Green & Bavelier, 2003). The importance of this finding lies in the capacity of games to alter brain structures via brain plasticity, which is nothing but a reflection of their capacity to produce learning. Similarly, action video game players show an increased sensitivity to salient visual objects in comparison to non-players, which can be attributed to the early sensory processing system which seems to be modulated by the action video game experience (West et al., 2008).

Under the premise that attention acts as a gateway for all learning, then due to the enhanced levels of attention that video game play generate, a potential for all types of learning through video games could be assumed. This would be particularly applicable to learning of a declarative nature due to the enhanced allocation of mental resources, such as attention and working memory, acting together to enhance the consolidation of memory. Similarly, the use of uncertain rewards in video games is associated with the release of the neuromodulator dopamine in the midbrain in areas involved in memory processing (Mason et al., 2017). The spikes of dopamine that occur when rewards are unexpected keep users more engaged but at the same time help them make better decisions based on the prediction of rewards, which in turn influences brain plasticity by reshaping the representation of the situation in the cortex based on a prediction error ratio (Schultz, 2016). The alternative explanation of learning through enhanced attentional resources may involve other aspects of video games such as moving objects, which may influence influence the deployment of attention.

The potential for learning attributed to action video game play is based on the evidence research has shown regarding the multiplicity of cognitive enhancements they produce which could be useful for learning (Bavelier et al., 2012). Video game play in this sense has been deemed as an enhancer of probabilistic inference, which means that it helps in learning to make better decisions based on the contrast between the information presented and that that is already stored (Ibid.). In other words, this concept of probabilistic inference is related to the educational concept of learning to learn. However, despite acknowledging that enhanced levels of attention may contribute to their impact on learning, the specific ways in which action video game play may affect attention are not yet established.

Some of the claims about the influence of action video game play and enhanced cognitive skills may be overshadowed by methodological concerns. The fact that most designs use extreme groups (players vs. non-players) leaves casual gamers out of the studies and much of the information concerning the middle of the distribution is not considered (Unsworth et al., 2015). Another issue regarding the claiming of effects of action video games on cognitive skills is related to the problem of transfer. Because the majority of games employed in this type of studies are not related to curricular areas, it is hard to assess whether these enhanced cognitive skills would be visible in better maths problem resolution, for example; or in an improved capacity for vocabulary learning and application. Evidence of skills transfer after video game play is mixed and not conclusive (Barnett, 2014).

One reason why educational video games may have shown mixed effects in the learning achieved by their players is that what seems to work for one group might not necessarily be as effective for another (Connolly et al., 2012). Some studies have shown that adult students (Beale et al., 2007; Papastergiou, 2009), adolescents (Arnab et al., 2013), and children (Suh et al., 2010) learn concepts or content knowledge better through the use of video games. However, some other studies have found that video games are as effective as traditional pedagogical interventions such as lectures, but that the latter produced better concept retention in the long term (Nishikawa & Jaeger, 2011; Rondon et al., 2013). Nevertheless, numerous studies have been unable to demonstrate a clear relationship between game play and enhanced knowledge acquisition, despite subjective reports of enjoyment and engagement with the game (Sward et al., 2008). It seems that other elements more related to pedagogical practices like feedback provision or face-to-face teaching seem to contribute more to learning than the sole aspect of competition involved in most of the gaming tasks (Cameron & Dwyer, 2005). This might be one of the reasons why video games are not being commonly used compared to other educational technologies for learning in educational contexts.

So far, most research findings related to the understanding of video games and learning have been at a descriptive level. There is the need to go beyond to the explanatory level of understanding, i.e. to be able to determine the elements and sequences of action in video games that would explain how such cognitive skills become enhanced through playing, especially in respect to attention, since its recruitment is closely associated with the capacity for learning. Dye et al. (2009b) suggest future research might focus on isolating the features of action video games that contribute to the observed changes in performance so that those features could then be associated with possible mechanisms involved in such change.

2.5 Summary of the chapter

This chapter has reviewed some of the computations the brain performs to learn and how all of them are linked by the mechanism of memory. In order for such computations to take place, attention – as the allocation of mental resources – is a prerequisite. Different attentional systems (alerting, orienting, executive) can be recruited when we learn. Declarative learning is one of the central types of learning that can be identified in educational institutions and is most related to the aims of this research. Despite its formation mechanisms not being entirely established, its dependence on the degree of attention allocation to target information from the environment is clearly present.

Action video games have been shown to recruit high levels of attentional resources and engagement. The relationship of attention and working memory leading to the consolidation of memory suggests that video games may have the potential for enhancing learning not only at a laboratory level but also in educational contexts. Hence, due to the complimentary connection between attention and working memory and the importance of their recruitment for learning, it becomes important to investigate the potential of attention-grabbing elements, i.e. motion of objects, that are typical features in commercial video games, as a means to enhance learning through an educational video game.

In sum, this chapter explored the interrelationship of attention, working memory and declarative memory formation as a theoretical basis for understanding learning in this research. This was used as a basis for arguing the potential of video games to enhance educational learning. It was pointed out that action video game play has been associated with driving enhanced attention as well as other cognitive abilities considered potentially relevant for learning in educational contexts. Evidence around the benefits of video game play for learning both at a cognitive and educational levels was also presented.

Chapter 3 Theoretical underpinnings for a relationship between game-like motion tracking and declarative memory formation

This chapter is a theoretical exploration of the links that can be established between one feature of video game play (motion) and its potential for enhanced declarative memory performance via the increase of attentional resources. The focus of this theoretical understanding will address the action of visually tracking single and multiple objects in motion and acting in response to their position and motion and its relationship to human cognition and behaviour.

Understanding of how key features present in video games contribute to the learning process has not been fully established. Considering the "value added" question type proposed by Mayer (2015) to investigate how games' features influence academic learning, this research seeks to understand whether the movement of objects might, through eliciting the player's attentive tracking, enhance declarative learning of factual knowledge relevant to academic learning.

Among the numerous behaviours required from an action video game player, the tracking of incoming and moving objects with the purpose of chasing and acting on targets is one of the most central sub-tasks of this genre. This is an activity that requires the allocation of sustained attention to various objects in motion over a period of time and also a shift in attention when cued to act in order to be successful in the game. An understanding of how key features present in video games contribute to the learning process, however, has not been fully established. This chapter seeks to establish the theoretical rationale for considering object tracking in the relationship between action video game play and declarative memory. It will address how visually tracking objects in motion might influence declarative memory formation for information about the object, through the involvement of enhanced attentional allocation.

3.1 The mechanism of visual tracking

Landscapes and physical environments are not normally static; they change dynamically, and individuals benefit from having a mechanism that allows them to visually grasp such modifications and keep representing them without losing their visual resolution.

Studies of animal cognition suggest that the primary use of this mechanism has been thought to serve the purpose of keeping track of prey (Bonanni et al., 2011) or to look for social companions (Bisazza et al., 2010). There is evidence of an object tracking system (OTS) across many species that acts as an evolutionary process that mediates the discrimination of a small number of items, namely up to four, even if they are moving objects and even if they are briefly occluded (Scholl & Pylyshyn, 1999). This mechanism seems to be linked to the process of subitising, which is one of the mechanisms humans use to establish numerosity (the others are counting and estimating), i.e. recognising the number of objects within a small group without the need for counting them (Chesney & Haladjian, 2011). Subitising is chiefly useful for small quantities (up to four). For the numerosity of larger quantities, another mechanism becomes involved referred to as the approximate number system (ANS) (Nieder & Dehaene, 2009). Trained fish (guppies) can better enumerate items in motion as compared to static when subitising, while they show no difference in performance when they observed larger quantities that were either moving or stationary (Agrillo et al., 2014), suggesting allocation of additional mental resource. However, this object tracking system does not seem to work for all animal species. Vonk and Beran (2012) conducted a study in black bears' cognition and found that they were better at enumerating static rather than moving stimuli. A plausible explanation for this difference in evolutionary terms was that, due to bears not living in social groups, there was no need for them to track individual members within a group and thus their tracking system may have not developed as in other species. Therefore, environmental factors related to the living patterns of species may have contributed to the evolution of the ability to track elements in motion as a survival skill.

Motion is easily detected by the human and non-human primate object tracking system (Royden et al., 2001). In a visual search study comparing humans and chimpanzees, Matsuno and Tomonaga (2006) found that both groups had difficulties in detecting a static item among objects in motion, implying not only that chimpanzees and humans share the same visual attention mechanism but also that the presence of motion is better detected than its absence. Nevertheless, human primates seem to have an advantage over non-human primates regarding the development of perceptual organisation in the detection of targets in dynamic scenes, i.e. the mechanism by which items are organised in groups according to their perceived motion coherence. This difference in perceptual organisation may be attributed to a general cognitive capacity that allows the recognition of different objects at the same time as well as the recognition of the spatial relationship among them.

In human developmental terms, the tracking of objects in motion has been documented as early as six months in babies tracking objects that were following a circular pattern of motion

(Richardson & Kirkham, 2004). Evidence shows that by the age of 6.5 years, children have the ability to track up to four objects in motion (Brockhoff et al., 2016; O'Hearn et al., 2010) but such ability declines with age. Older populations' (+60 years old) tracking performance declines with the tracking of four objects simultaneously but can be well maintained with an average of three and is definitively accurate while tracking one object. This eliminates explanations of age-related insensitivity to motion or maintenance of concentration (Trick, Perl, et al., 2005).

However, a later study by Sekuler and colleagues (2008) that also compared young and older subjects in their tracking performance suggested that Trick, Perl et al. (2005) may have omitted a covariate associated with age-related experience, such as the influence of video game play. There is evidence that visual attention is altered by regular video game play (Green & Bavelier, 2003; Riesenhuber, 2004) and that this experience is most prevalent in young adults. The study by Sekuler et al. (2008) confirmed that the groups that play video games regularly had a better performance in multiple object tracking tasks, establishing an age-related difference associated with this experience. Furthermore, participating in action sports may also act as a covariate in multiple object tracking performance among children (Trick, Jaspers-Fayer, et al., 2005).

The benefits of elements in motion compared to static can also be appreciated in how eye gaze is directed more prominently to moving elements. In a study that explored the benefits of motion in animated storybooks, Takacs and Bus (2016) found that children tended to recall more language items from a story that contained animated illustrations as more visual attention was given to objects in motion than to static illustrations. The link between motion and attention allowed for enhanced memory of items learned in such a condition, and consequently to higher levels of comprehension through animated moving characters solely as the task did not contain sounds (Ibid.). Similarly, observing another individual performing an action, also referred to as enactment, can influence cognition positively. Examples include better recall of words that have been learned by performing their corresponding action than when learned through mere verbal tasks (Engelkamp et al., 2004; Heil et al., 1999). However, this is not exclusive of word meanings as demonstrated by Lindemann et al. (2007) who used Arabic digits (that also entail semantic information) to explore the functional connection between action planning and numerical cognition showing that semantic effects on motor actions were not restricted only to words. These findings suggest that semantic information processing and action seem to have an interdependence regardless of the nature of the semantic knowledge (Gallese † & Lakoff, 2005).

Goal-orientated visual tracking has evolved as a trait in many species who rely upon it as a mechanism of survival. Being able to make meaning from a dynamic scene and act over it is likely to require the deployment of additional cognitive resources such as attention and working memory (Itti & Koch, 2001). The allocation of attention in dynamic scenes has been studied experimentally through the development of ad-hoc tasks that will be explained in the following section. This paradigm will be reviewed as it provides a theoretical basis for hypothesising that tracking objects in motion may enhance declarative memory formation.

3.2 The experimental study of visual tracking

The visual tracking of objects in motion and its mechanisms have been experimentally studied through the Multiple Object Tracking task (MOT), firstly developed by Zenon Pylyshyn around the late 1980s (Pylyshyn & Storm, 1988). This task has been widely used to research object tracking as well as its implications for visual attention and working memory (Meyerhoff et al., 2017). It consists of a very simple task (Figure 3.1) that begins with observers seeing a number of identical objects on a screen out of which those with the status of target are flashed for several seconds. After this, all objects become unidentifiable again and they start moving around in an unpredictable way. When they stop moving, observers need to indicate which ones the targets were (Scholl, 2009).

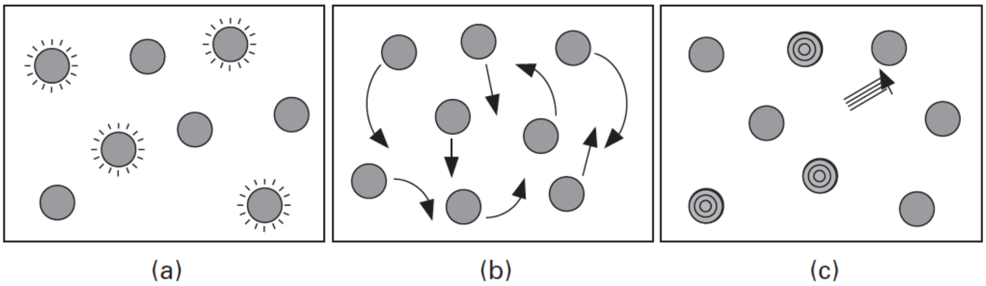


Figure 3.1. Multiple object tracking (MOT) task. (a) On an initial screen with identical objects, four are highlighted as targets. (b) The objects all in their original form start moving around in different directions. (c) When objects stop moving, the observer marks the ones that are thought to be the targets using the computer mouse (adapted from Scholl, 2009).

Nevertheless, because in real-world scenarios objects are distinctive from one another, a more meaningful task was needed to deepen the understanding of motion object tracking. An

MOT-like task that included the semantic meaning of the objects being tracked was then developed, the Multiple Identity Tracking (MIT) task (Oksama & Hyönä, 2004). This variant of the MOT task uses objects that are distinctive with respect to shape, colour or category information, requiring the observer to track the objects as they change locations. In other words, the observer has to recognise and relate the target's location and its identity, i.e. the binding of the "where" and the "what" (Treisman, 1996) (Figure 3.2). Therefore, this paradigm seems more appropriate to interpret tracking occurring in natural settings, as it incorporates the idea that objects are mostly distinctive and entail specific semantic information or conceptual knowledge besides their surface features (Wei et al., 2018).

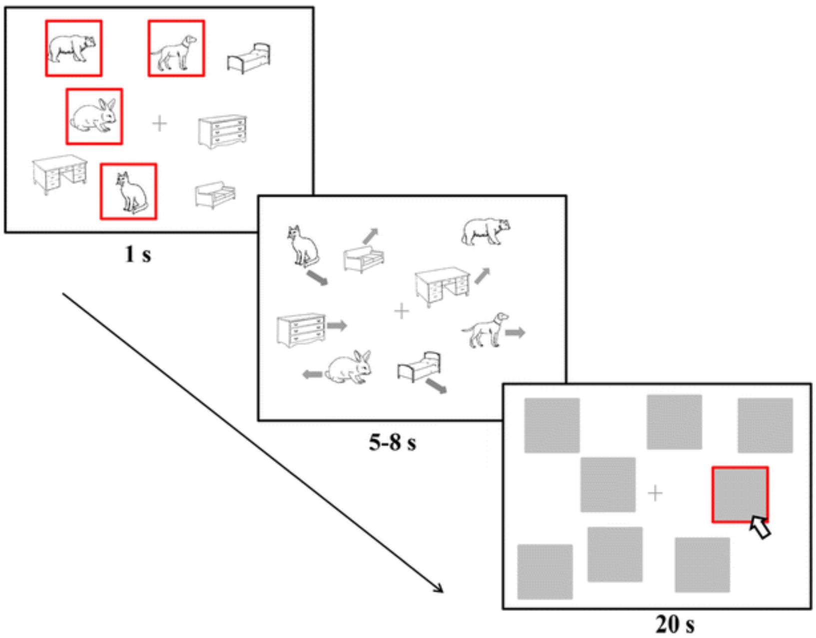


Figure 3.2. Example of a MIT task with two categories of objects (animals and furniture). Following the same principle of MOT, all the objects are shown and then the targets are highlighted. After that, they start moving in different directions. When movement stops, objects are masked and participants are asked to indicate the targets with, for example, the mouse (Wei et al., 2018).

Only one model of the mechanisms involved in the tracking of multiple objects with semantic identity has been developed to date – the *Model Of Multiple Identity Tracking* (MOMIT) (Oksama & Hyönä, 2008). This model characterised tracking as a serial mechanism based on attention switching processes that, in turn, would involve the working memory components. A multi-component understanding of working memory was used to explain its involvement in the process of tracking. This comprised an episodic buffer for the identity-location bindings, a visuosketchpad for the indexed location information, and the recourse of long-term memory as storage of the dynamic binding (Oksama & Hyönä, 2008). This model involves a serial refresh process, thereby suggesting that rapid switching of the attentional focus provides the basis of successful tracking (Huang et al., 2014). The understanding of attentional tracking of semantic identities based on these principles of serial processing and interaction between attention and working memory is the model that this research will adopt to design the gaming task and explore the research question.

Five empirically-supported tenets underpin this model that might contribute to the understanding of the role of attention and working memory in visual tracking. First, the model includes the notion of constantly refreshing the identity-location binding by means of an effortful and non-automatic processing of attentional shifts between targets. Second, the model assumes limited-capacity storage for the number of bindings actively maintained at the same time. A third tenet attributes LTM participation in the representations of temporary bindings, i.e. that familiar targets are more readily bound than unfamiliar objects. Fourth, the model vindicates the use of visual short-term memory (VSTM) as the temporary storage unit for the spatial indexes representing the location of the tracked objects. Finally, the fifth tenet makes reference to an extra source of information for the attentional shift mechanism provided by peripheral information that is not indexed (Oksama & Hyönä, 2008). This very detailed model has been streamlined into a very recent version – *MOMIT 2.0* (Li et al., 2019) – which adds to the components the concept of situational awareness during tracking. This is the perception and comprehension of critical information during the tracking task that allows making use of past and present information to make future decisions related to the task (Endsley, 2000; Saus et al., 2006).

The MOT task and its variants have mostly been used in laboratory settings and there is little research using more realistic contexts, such as sports or children's playground, with the exception of research in the area of transport and driving (Lochner & Trick, 2014). It has been, however, fertile in providing evidence that links visual tracking with attentional and memory processes. Though this research will not use an actual MOT or MIT task among participants, their supporting paradigm shares the notion of attention that can be elicited through video game mechanics by emulating an object tracking situation that enables the interaction of attention and working memory. In most common action video games, players need to look for task-relevant information in the form of moving targets while rejecting task-irrelevant moving distractors. Therefore, the principles of how attentional resources are recruited via a tracking task – especially for objects with identity – serves as support for the experimental exploration of the potential relationship between video game play and declarative memory via enhanced attentional recruitment. Additionally, understanding how tracking best operates in terms of performance can inform aspects of game design to recreate a situation in a game-like task that elicits tracking of moving objects optimally.

A series of different theories have originated from the use of the MOT task in research. They are an attempt to explain how tracking is perceived and affects the way we act upon the multiple objects in motion. However, despite years of research, there is still not a unified version for understanding the mental processes involved in the visual tracking of multiple objects and the way they operate. This lack of agreement has also become the source of three debated dichotomies (Scholl, 2009). First, whether tracking should be considered a parallel or a serial processing, i.e. whether objects receive attention all at the same time or attention is directed to one after another. Second, the way in which the object's identity and location bind to make sense, i.e. whether attention deployed to location only or to location and identity to create the binding and update it. And the third dichotomy refers to the actions conducted in relation to the objects being tracked, i.e. whether objects are grouped or segregated in order to enhance tracking performance.

3.3 Multiple object tracking, attention and memory

Although it was not originally created for studying attention, the MOT task and its variants have served to illustrate the engagement of attentional processes involved in the tracking of objects in motion (Scholl, 2009). However, the original authors of the MOT task presented a more subtle relationship with attention in their initial studies by suggesting that tracking was a preattentive mechanism (Pylyshyn & Storm, 1988) that cannot be cognitively engaged (Pylyshyn 1999). The original approach to multiple object tracking was based in the Visual Indexing Theory – known as FINST Theory (FINgers of INSTantiation) that establishes a limited number of tracking 'pointers' (approximately four) that can be attached to objects in motion. It is based on a parallel understanding of the visual system as it can index (or point at) multiple objects at the same time. This mechanism was considered a preattentive and automatic one that did not require an effort (Pylyshyn, 1989). Considering tracking as a preattentive task follows the understandings of motion tracking as a primitive activity (Scholl 2009). However, further research has shown that tracking objects in motion requires a continuous utilisation of visual attention in order to maintain the information in the working memory and avoid confusions among the objects in case a response is needed (Meyerhoff et al., 2017). Later work by Pylyshyn (2001) reconsidered the 'preattentive' property of his theory and changed it to 'preconceptual', finally giving attention an involvement in his theory. Furthermore, when objects bear an identity, the binding identity-location requires effortful sustained attention (Wheeler & Treisman, 2002). Huang and colleagues (2012) showed in an extensive study the interrelation of different visual attention paradigms and concluded that visual tracking was highly correlated with a general attention factor, which acts as a representational resource that in greater quantity leads to superior performance. Regardless of the different names attributed to visual tracking (*multifocal attention* by Cavanagh and Alvarez, 2005; or *attentive tracking* by Fougnie and Marois, 2006), the MOT paradigm encompasses three core aspects of attention, namely its selectivity, its capacity limitation, and its effortful processing (Pashler, 1998). Scholl (2009) summarises four aspects that illustrate the relationship between the multiple object tracking task and attention. First, tracking multiple objects in motion requires the use of sustained attention over time instead of short attentional shifts. Second, MOT instigates the deployment of attention to several objects and not just focal attention to one object. Third, MOT is in nature an active task that requires action from the observer rather than a vigilant state only. Finally, the task allows for a direct manipulation of its attentional demands based on the tracking load presented. These elements provide the task with a level of ecological validity to represent real-world dynamic scenarios, such as video game play. Therefore, this research will adopt the notion that the MOT paradigm supports the involvement of sustained attention in the task of tracking objects in motion, but also including shifts of attention between sustained and divided attention, as processes that lead to the activation of other mental resources in order to keep track of targets and their locations.

Attention is not only used to track motion but is also split during tracking to allow tracking of multiple objects at the same time, in a parallel fashion. Based on a similar idea to the visual indexes system, Cavanagh and Alvarez's multifocal attention theory (2005) proposes the introduction of attention into the equation, as tracking requires individuals to attend to multiple foci but again with limited attentional resources allocated. They propose that attention focus can be split, allowing for continuous attention to be displayed to all objects being tracked. The researchers found that twice as many targets could be tracked successfully when they were distributed across the left and right hemifields instead of locating them all in a single hemifield (Cavanagh & Alvarez, 2005). After experimenting with the number of objects to be tracked in relation to their speed, Alvarez and Franconeri (2007) proposed that the allocation of attention between the objects being tracked can be flexible and its variability depends on properties such as the speed and proximity of the objects. Therefore, errors in tracking performance appear when attention is not sufficient enough to cover the demands of such targets, e.g. the speed of the object trajectories is too high to be able to track correctly. Their findings originated the Flex Theory which added an element of flexibility to the allocation of mental resources while tracking, but without establishing whether it occurs in a parallel or in a serial fashion. This theory draws on the multiple combinations of structural constraints, and the sense that it might have a fit for every possibility makes it vague and not scientific enough (Meyerhoff et al., 2017).

Due to the nature of the MIT task, in which not only location but also identity are part of the tracking performance, the debate around the deployment of attention for these two elements relates to whether this is a one- or a two-stage process (Pinto et al., 2012). In a one-stage process, attention has an initial role in the location of the targets, but no longer attentional effort is required for the identity. However, two types of attention are involved in a two-stage process, namely attending to the location and to the identity of the target in the already identified location. Cohen et al. (2011) observed that participants to their study could choose either the location or the identity element of the MIT task and that by doing so, the non-elected task had a lower performance, suggesting a common resource from which both tracking mechanisms (for location and identity) would draw upon. Furthermore, a study by Hu and colleagues (2018) on identity-location binding at the attention stage provides a deeper understanding of the processing systems involved in location and identity binding. By altering the moving stimuli identities to establish the effects of identity switch in the MIT task, the study showed that both location and identity processing systems shared the same attentional resource, as shown previously by Cohen (2011), but the location information received priority from the visual system over the identity information (Hu et al., 2018). Moreover, these attentional resources are used to enhance the visual resolution of targets rather than distractors in an MIT task.

The MOMIT (Model of Multiple Identity Tracking) assumes the multiple identity tracking task as a serial process that involves not only attentional resources to maintain the resolution of the bindings but also visual short term memory and working memory to store identities and update their locations (Oksama & Hyönä, 2008). Performance in tracking is affected negatively as a function of time and object set size (Oksama & Hyönä, 2004). It decays with extended time and with bigger sets of objects to be tracked. In its most recent version, the model has involved eye movements in this loop as the eyes select the next move according to certain conditions established in order of priority. First, the eyes move to an unattended object whose resolution is declining; second, the eyes move to a peripheral object with high resolution; and third, the eyes move to a blank area with multiple objects (Li et al., 2019). Oksama and Hyönä (2016) involved eye movement to establish the different fixation strategies used in both MOT and MIT. While the tracking of targets (MOT) tends to fixate on the centre to track targets, the tracking of identity (MIT) uses an attention switch fixation strategy, which makes it a serial process compared to the parallel nature of the MOT task. Additionally, eye movements were more frequent in the identity tracking due to the shifts of attention to allow the refreshing of spatial-temporal information that would increase the resolution of the sampling. This suggests that there are two separate sub-mechanisms for tracking that act depending on the nature of tracking, either for location or for identities. These steps in the MOMIT provide a framework to understand the way whereby attentive tracking to objects with semantic identities involves selective attention and working memory to maintain bindings and also reinforce the category information of targets. The model supports the notion that tracking objects in motion involves mental resources that may enhance declarative memory if conditions of tracking are in line with those that support tracking performance.

Based on the notion of the common attentional resource shared for tracking location and identity for the MIT task (Cohen et al., 2011; Horowitz et al., 2007), Hudson and colleagues (2012) proposed that real-world object tracking might be best conceptualised through a model that combines both MOT and MIT paradigms. This combined model is based on a first stage that would inform the locations by segregating targets from distractors, via multifocal attention like in the FLEX model (Alvarez & Franconeri, 2007), but with the sole difference that Hudson et al. (2012) assumed that tracking operates in each cerebral hemisphere separately and that each of the hemispheres can track objects in both left and right visual hemifields. The second stage builds on this information and relates identities to each target. This process is serial, i.e. each target is attended to individually and its identity remembered. This suggests the involvement of working memory and attention in the maintenance of the binding while tracking information similar to the MOMIT in which the location-identity is allocated in working memory and updated through attention switching.

At a neural level, research has shown increased BOLD activation in dorsal frontoparietal attentional network during multiple object tracking. These include the intraparietal sulcus (IPS) and superior parietal lobule (SPL), which show a high level of engagement during tracking even when their roles in function are distinct (Alnæs et al., 2015). Culham and colleagues (1998) first identified eleven areas that were sensitive to attention and also motion detection and eye movements. Several other brain regions have been associated with tracking and attending to objects using MOT (Alnæs et al., 2015; Culham et al., 1998; Jovicich et al., 2001) without necessarily having made a distinction between those two processes (Howe et al., 2009). The FEF (frontal eyelid field) and the SPL show activation in a MOT task when attention is directed to moving rather than static objects. Instead, static objects activated the posterior intraparietal sulcus (PIPS). The human motion area (MT+) is activated with attention directed to both moving and static objects, suggesting its potential role in updating location information (Howe et al., 2009). The anterior intraparietal sulcus (AIPS), which has been previously described as an attentional area for general purpose (Corbetta & Shulman, 1998), seems to be only activated with moving targets, suggesting its main involvement is in tracking objects rather than attending to them (Ibid).

Wei and colleagues (2017) studied the neural basis using the MIT task, particularly the aspect of using the objects' category information to segregate them as distractors or targets. They identified the activation of left fusiform in charge of processing and maintaining the semantic representation of the object, and the pars triangularis in the inferior frontal gyrus (IFG) in the classification into two semantic categories (animals and tools in their study). The anterior cingulate cortex (ACC) also had a role in initiating and maintaining category-based grouping representation and with an inhibitory role to avoid the disruption produced by distractors. These brain regions involved in the tracking of objects with identity reveal the involvement of attention to initiate behaviour and memory to contribute to the processing and representation of objects.

The switching of identities that occurs in MIT has also been studied at brain level. The study by Lyu and colleagues (2015) confirmed the activation of the frontal eyelid field when observers focus attention to targets to bind their identities and locations as they track. Contrary to the study by Howe et al. (2009), Lyu (2015) found a high activation of the IPS when observers had to attend to switching targets rather than when the switching was among distractors, which revealed an enhanced level of attention to targets that switch identities. However, when the switching involved distractors, the IFG and pars orbitalis were activated which was interpreted as a stimulus-driven attentional effect. Both FEF and IPS are regions involved in the dorsal attentional network and are known for strengthening goal-driven attention, while the IFG-Orb is associated with the switching of attention. These imaging studies are a confirmation of the attentional resources recruited in identity tracking established by previous behavioural studies. Tracking objects in motion requires levels of sustained attention as well as divided attention to maintain a good level of performance in the task. This necessarily draws in the mechanism of working memory that helps maintaining the levels of representation of the binding. Eventually, this rehearsed representation reaches a longer-term storage that would enable a more accurate and faster recognition of the bindings over time.

The experimental study of motion tracking through MOT and MIT tasks has not only provided evidence of the mental mechanisms that the activity draws on to complete it successfully. Research using these tasks has also informed on how the elements to be tracked and some of their features and interrelationships may well facilitate or hinder the tracking performance. This evidence illustrates the involvement of attentional processes and working memory in tracking motion and identity. It has also informed aspects of the design of the task to be used in this research, which considers the action of tracking moving objects with semantic identity but differs in some aspects of the dynamics of the MOT/MIT paradigm. They will be reviewed as follows.

3.3.1 Elements that facilitate or impair visual tracking

One of the first things we know about performance in visual tracking relates to the number of objects that can be simultaneously tracked and keep the appropriate levels of attention in order to succeed in the task. Besides the optimal number of objects, under MOT or its variants, attention performance can be associated with different factors involved in the tracking of moving objects, such as physical (Makovski & Jiang, 2009a) and conceptual (Wei et al., 2016) properties of the objects being tracked, the space between them (Zhao et al., 2014), and the speed with which they move (Alvarez & Franconeri, 2007). These factors have been shown to influence the way in which objects are tracked and the tracking accuracy, which consequently implies the levels of attention deployed to complete the task. Besides the influence of these elements in tracking performance, the interplay between tracking, attention and working memory becomes relevant in the tracking of distinctive targets (Allen et al., 2006; Oksama & Hyönä, 2004, 2008).

The number of targets seems to influence the tracking ability (Oksama & Hyönä, 2004). As explained earlier, based on a parallel understanding of the visual system that can index multiple ‘pointers’ (as established by the FINST theory) at the same time, the limit in the number of objects to be tracked is approximately four (Pylyshyn, 1989). These pointers are attached to the objects in motion and they become units of attentional selection (Scholl et al., 2001). With age, performance declines and the number of objects to be tracked also diminishes, but the tracking capacity remains as shown by Trick, Perl et al. (2005).

The traditional MOT task does not consider the surface properties of the objects being tracked. In fact, most studies using MOT have shown that tracking involves mainly a spatiotemporal updating of the object, i.e. observers can report locations and directions of the objects but rarely their colour or shape (Scholl et al., 1999). Research using the MIT task has shed light on how surface features of objects in motion affect tracking as well as their identity-location binding (Wei et al., 2018). Tracking performance can be affected positively or negatively given the distinctiveness of the objects (Liu et al., 2012). A version of the task using cartoon animals with unique identities showed that observers' capacity to indicate location was superior to that of identity reporting (Horowitz et al., 2007). This confirms the notion that surface features are seldom elicited in attentive tracking and also suggests that the representation of the moving target might be processed by two different systems, one for location and one for individual identities. However, Makovski and Jiang (2009b) suggested that by mixing elements of both tasks – MOT and MIT – it was possible to examine attentive tracking without the interference presented by dual-task requirements that impede tracking and remembering features in a balanced way. In their location-tracking task, performance was improved when the objects were unique in colour, but they also found that visual working memory for features and for tracking motion work in parallel but independently from each other (Makovski & Jiang, 2009a). Therefore, distractors may have an effect on tracking depending on what has been established for the target features from a top-down perspective. A video game play situation provides a context which is guided by established top-down rules regarding the tracking and acting upon targets and distractors, and will also act as a goal-directed behaviour which can be modulated by salient stimuli that needs to be distinguished first based on the rules related to surface features that provide meaning.

Additionally, the use of distinct features in distractors, e.g. shape, colour, motion, compared to targets has shown to interfere less with tracking performance than if distractors were identical to targets (Feria, 2012). Nevertheless, the opposite effect occurred in an experiment that used faces as objects to be tracked (Ren et al., 2009). When unique faces were used, tracking performance was impaired as compared to the use of identical faces. This relationship between objects' uniqueness and tracking performance (enhancement or impairment) seems to depend on the objects' visual complexity (Liu et al., 2012). In their study, Liu and colleagues (2012) asked participants to track numbers of different complexity (1 or 2-digit numbers or 3- or more digit numbers). They found that when objects were less complex, i.e. they are 1 or 2-digit numbers, uniqueness identity would enhance tracking. The opposite happened with 4-digit numbers. Previous research has demonstrated that the longer verbal content takes to be vocalised, the briefer it remains in the short-term memory span (Hulme & Roodenrys, 1995). In the case of numbers, those with longer digits would be vocalised in a longer time. Therefore, the difficulty in the processing of identity information implied in the study by Liu and colleagues would lie in working memory capacity to deal with the complexity of the objects. Hence, more visually complex objects (such as single or complex digit numbers, or Chinese characters) would be retained for less time span in working memory and the processing of the identities would require extra cognitive resources that may interfere with the attentive tracking processing in the form of additional cognitive load (Liu et al., 2012).

The level of familiarity of the object being tracked is not considered a benefit associated with better memory for targets and distractors but as a factor that would tend to improve the tracking (Oksama & Hyönä, 2008; Pinto et al., 2010). Whether MIT is considered a one-stage or two-stage model, familiarity of targets facilitates tracking performance, but only in the two-stage model understanding of MIT; this easier identification can be associated with a reduction in the effort made to identify the object, i.e. less attention is required, alleviating the processing (Pinto et al., 2012). A brain study on tracking familiar and unfamiliar objects showed that different networks were activated depending on this feature. Familiar items recruited naming and memory areas in the resting state network, while unfamiliar objects recruited networks associated with attention and visual identification. The two different networks that were recruited not only supported a two-stage model of MIT, but also the notion that familiarity of objects optimises the allocation of attentional resources as well as the capacity to identify (by remembering) objects when attending their location in MIT tasks (Pinto et al., 2012).

Regarding the influence of semantic category information of targets, a consistent advantage in tracking accuracy has been shown even with a minimal difference among targets and distractors (Wei et al., 2016). However, the reasons for this advantage and the mechanisms behind remained unclear until an extensive study by Wei and colleagues (2018). Trying to understand how semantic category information facilitates tracking performance, the researchers concluded that what tends to facilitate tracking in MIT is a mechanism to group targets based on their category. Through multiple experiments, they discarded –not completely, however – the influence of visual distinctiveness between targets and distractors; of attentional distribution as a consequence of the category distinction between targets and distractors; and of working memory when targets and distractors belonged to different categories. The observers' strategy of segregating targets from distractors to eliminate interference and facilitate tracking is effortful and goal-directed, i.e. observers decide to incorporate this strategy or not depending on the circumstances of the task (Wei et al., 2018). Most importantly, their finding shows the semantic identity entailed in the objects is processed beyond the perceptual level to the knowledge representation level, which influences the way of encoding information and remembering it – at a categorical level – which leads to declarative knowledge formation (Ibid.).

The MOT and MIT tasks have also been used to study the field of expert populations that require high levels of visual attention for objects in motion, such as radar operators (Allen et al., 2004), sports players (Memmert et al., 2009) and video game players (Green & Bavelier, 2006a; Sungur & Boduroglu, 2012). In the case of video games, the study by Green and Bavelier (2006a) used the MOT task to compare video game players versus non-players in their tracking capacity of tracking multiple moving objects and later trained the non-players, suggesting that the enhancement in the number of objects that can be tracked in the MOT task can be attributed to action video game play and is mediated by changes in visual short-term memory skills (Ibid.). Similarly, but using the MIT task, Sungur and Boduroglu (2012) demonstrated that video game players could better track moving objects and maintain their identities compared to a group of non-players, which confirms what other studies have suggested about video game players' greater attentional breadth that enables their better performance (Feng et al., 2007; Green & Bavelier, 2006a, 2006b). Video game players have shown to have enhanced cognitive abilities as a result of playing games that contain the feature of tracking and acting upon objects in motion, like in the MOT/MIT tasks.

Tracking objects in motion is a mechanism that has allowed for survival and thus is connected to learning. Tracking requires the deployment of attentional resources, particularly sustained attention that enables the identity-location binding, but it also requires divided attention in order to segregate distractors from targets. The shifts in attention to the different objects are required to refresh the bindings which are temporary stored in the working memory. Different elements, such as number, colour, movement related to the objects being tracked can either promote or interfere with tracking performance, which corresponds to the capacity of accurately locating the bindings (location-identity). When objects have a semantic identity, a process of categorisation takes place which takes the identity processing to a conceptual knowledge level that may eventually reach declarative memory formation. This principle behind tracking of objects in motion with semantic identity is part of the theoretical support of the exploration of the research question in this project.

Another sub-task present in video game play and that relates to the tracking of objects in motion is that of changing attention towards a cue in order to take action. These shifts in attention as a result of a cue detection trigger an action that has consequences to the task being performed. They involve processes related to attention and encoding of memories and are reviewed in the next section.

3.4 Shifts in attention, cue-directed action and memory

Tracking multiple objects in motion will necessarily trigger mechanisms of attention previously described. Besides a combination of sustained and divided attention necessary to maintain location and identity of targets among multiple moving objects, video games promote changes between modes of attention, e.g. a transition from divided to focused attention that allows the selection of information and consequent action when a cue is detected (Bavelier & Green, 2019). This mechanism has been identified as orienting attention towards a salient stimuli according to the attentional systems described by Posner and colleagues (1980). A further process in the string of attentional mechanisms would be that of cue detection that enables the capture of the information about the stimulus in order to process it and activate a response (Posner et al., 1980).

There is evidence for a neuronal mechanism that supports attentional shifts from monitoring for cues to cue-directed behaviour via the release of cholinergic transients which is directly observable in rodents and as a proxy for BOLD in humans (measured through tissue oxygen in rats) (Howe et al., 2013). Animal research has worked with previously trained rats using the Sustained Attention Task (SAT), a task requiring a signal detection and a non-signal rejection (press lever A with one stimulus and lever B with the lack of it; correct hits are rewarded) while they are connected to microelectrodes to measure cholinergic activity. A range of studies (Gritton et al., 2016; Howe et al., 2013; Parikh & Sarter, 2008) have recorded real-time acetylcholine – a key neuromodulator involved in attention and memory – release peaks in the right prefrontal cortex (rPFC) when signal trials were hit but also when they were preceded by an incongruent hit (i.e. before the correct hit, there was a real or a perceived non-signal event). In humans, a BOLD signal was measured for a similar task and the equivalent brain region was involved in the same type of hits (incongruent hits), correlating greater activation with faster response times. The increment of cholinergic activity via the SAT is revealed in increased levels of acetylcholine in the rPFC in rodents and in brain activation in the same region in humans. Cholinergic release in the prefrontal regions is not only associated with the activation of executive functions but also with the anterior attentional system (Sarter et al., 2006). This greater activation in humans was also correlated with faster response times, which is evidence of a cholinergic signalling (Howe et al., 2013). These findings suggest the involvement of cholinergic transients in cue detection that involves a shift from a state of monitoring to the activation of a cue-directed response or behaviour (Sarter & Lustig, 2019).

Acetylcholine is a key neuromodulator involved in memory and attention (Rokem & Silver, 2013). Research has shown that the release of acetylcholine in the prefrontal brain regions acts as mediator in the detection of cues (Sarter et al., 2005) and in the actual mechanism of orienting (Dye et al., 2009a). In humans, brain regions that show activation via pharmacological manipulation of cholinergic receptors coincide with those involved in processes of attention such as attentional focusing, filtering and orienting which are part of selective attention (Klinkenberg et al., 2011). Acetylcholine release in the hippocampal and prefrontal brain regions is thought to have a function in memory encoding. This neuromodulation is increased with novelty (Giovannini et al., 2001) and establishes a novelty-dependence relationship that modulates the brain encoding mechanism (Easton et al., 2012). Kukolja et al. (2009) showed that encoding and retrieval of episodic memory was not equally influenced by acetylcholine stimulation. While memory encoding was improved, its retrieval seemed to be interfered at a neural level. Since changes in acetylcholine levels may act favourably or detrimentally depending on the phase of memory, Micheau and Marighetto (2011) separated the memory stages (encoding, consolidation and retrieval) within different time frames when studying the cholinergic biphasic hypothesis. They showed this biphasic influence to be helpful in the coordination of different memory systems. Hence, higher cholinergic activation in the hippocampus when a task is performed will imply a facilitated processing of new input (encoding). A decrease in the cholinergic activity, that occurs when the task has been finished, leads to the consolidation of such information (Hasselmo, 2006; Micheau & Marighetto, 2011). These findings in the differential effects of acetylcholine release might be relevant when considering an intervention in which the release as well as the decrease of cholinergic activity need to be coordinated in order to foster a better learning. Therefore, acetylcholine has different forms to influence possibly all memory systems (Van der Zee et al., 2011). However, this linking of acetylcholine to cognitive processes does not include evidence for enhanced declarative memory formation via cue-directed behaviours, but it can be reasoned that such enhancement might eventually occur due to the hippocampal projections of acetylcholine, as a result of attentional shifts.

A study using a 3D version of the MOT task showed that the pharmacological manipulation of the cholinergic neurotransmission via Donepezil – a drug commonly used for Alzheimer's disease patients – in a young healthy population did not have an effect in the visual processing (tracking skills) compared to the control group. The study used a training paradigm in which the 3D MOT was completed over 5 sessions. The drug group showed a learning effect on day four while both groups showed this effect on day five. Post measures (4-14 months later) evidenced the long-lasting effects of cholinergic manipulation via drugs and support the idea that higher cholinergic transmission has an effect on encoding information from attentionally-demanding cognitive tasks (Chamoun et al., 2017).

The high attentional demands involved in action video game play in which the actions of shifting from sustained to divided attention (like in a MOT/MIT task) can be hypothesised as having an effect on the peaks of cholinergic activity observed in shifts of attention from a monitoring state to cue detection. In action video game play is an activity that improves top-down allocation of resources that can lead to enhanced selective attention and better representations of the objects on screen (Bavelier et al., 2012). As previously stated, attention, understood as a cognitive resource allocation process, is key for learning because it helps refine the distinction between signal and noise in relation to a goal, which increases the precision of perceived information. In a tracking and identification task (MOT, SAT, etc.), the more accurate the level of the representation is, the more accurate the task performance will be (Boot et al., 2008; Green & Bavelier, 2006; Trick, Jaspers-Fayer, et al., 2005). Since acetylcholine has a key role as a neuromodulator that alters brain circuitry as a result of changes in the environment (Picciotto et al., 2012), researchers in video game play have suggested that the detection of cues that prompt an action from players may enhance probabilistic inference learning, i.e. may generate an increased learning (Bavelier et al., 2012). The interconnection of mental mechanisms is considered to help in the integration of external cues with internal representations of actions in order to start and guide behaviour (Howe et al., 2013). However, there is no established direct link between video game play and cholinergic activity (Bavelier et al., 2012).

The shift of attention to act on cues that occurs as part of the subtasks of video game play seems to have a cognitive basis for learning based on the neuromodulation effects of acetylcholine on areas associated with attention and memory encoding. However, research exploring the influences and processes of the cholinergic activity reveals the need for further studies to test theories emerged from experimental research in cholinergic activity mediated by cue-directed action (Howe et al., 2013; Sarter et al., 2014). Research so far has pointed to target cholinergic dysfunction and enhanced treatment from a pharmacological perspective. An exploration of these hypotheses could, therefore, potentially be helpful for application in educational areas through technologies that simulate cues requiring action, forcing a shift from a monitoring state to a cue-directed behaviour that allows major cholinergic inputs and its expected consequences in memory encoding.

The present research considers the relevance of attentional resources in learning and underpins its understanding on evidence from motion tracking and cue-directed action. In order to explore the potential relationship between video game play and declarative memory formation, attentional processes will be elicited through game-like tasks based on the features of attentive tracking and cue-directed action.

3.5 Research questions and hypotheses

The proposed research aims to further understand how educational learning can be enhanced through technology-based game play involving motion of objects with semantic information. Declarative learning, i.e. factual knowledge, is a type of learning developed in educational contexts. This research will use prime numbers as a mathematical fact to be learned through a learning game featuring motion. Based on the explanatory theory linking visual tracking of elements and the deployment of attentional resources to support the binding of location and information, it can be hypothesised that moving stimuli will be recalled faster and more accurately than static stimuli presented in a learning video game-like task.

Hence, the following main RQ will be researched:

RQ_main ***What is the influence of the movement of learning stimuli, tracked as part of an educational video game-like task, on the declarative memory of their properties, as measured by accuracy and speed of recall?***

The following hypotheses will be explored to investigate learning through an motion-based computer game, in which individuals must track and act upon a moving target in order to respond:

H_1: Accuracy of responses will be significantly higher for numbers learned under the motion condition compared with those under the static condition measured by the difference between pre and posttest.

H_2: Response time will be significantly lower for numbers learned under the motion condition compared with those under the static condition measured by the difference between pre and posttest.

3.6 Summary of the chapter

This chapter has theoretically explored how attention and memory have been studied through experimental tasks that share similarities with the sub-tasks performed in video game play. Visual tracking, as a human and animal capacity, triggers attentional resources that allow for a better representation and encoding of the moving objects being tracked through a refresh of the objects' location and semantic identity. It is possible that this processing of semantic identity may enhance declarative memory for it. Similarly, the mechanics of an action video game induces change in the attentional state of the observer in a dynamic process that begins with a monitoring state, as the observer waits to detect a cue that would enable an action. Research has shown that such cue-detection may prompt the release of the neuromodulator acetylcholine in the neocortex and hippocampus, which are regions linked to declarative memory formation. This action is guided by goals and it is intricately related to the processing of semantic information of the objects being acted upon. This theoretical understanding of cognition in dynamic environments will guide this research in exploring how tracking and acting on moving objects characterised by semantic information as part of an educational video game-like task may enhance the declarative learning of such semantic information and contribute to educational learning.

Chapter 4 Approach and methods used in this research

This chapter addresses the approach to this research and the methods used to explore the research question. The first part addresses philosophical issues encountered when researching in the field of neuroscience and education and how the concept of *learning* becomes problematic when understood from both the social and natural sciences' perspective. Based on explanatory frameworks proposed to understand research in educational neuroscience, this particular study is situated with an aim to guide the design of the methods used and the reasoning behind the need for laboratory studies to shed light on issues of the social world such as the educational field. Hence, a second section delineates the methods used in this research, making a case for the need of a particular type of task that is ecologically valid from an educational neuroscience perspective. This also includes explanations for the measures used to understand learning as well as the design process involved in the instruments used to collect and analyse data, general procedures and data analysis used with more detailed information contained in the corresponding chapters.

4.1 Issues of a transdisciplinary science

This research explores processes involved in human learning from a brain-mind perspective, i.e. considering theories and methods proposed by the field of neuroscience to inform educational practice, a field more identified with the ontology of the social sciences. This combined field has been proposed under the name of educational neuroscience (other names are also used to refer to the same field, *neuroscience and education*, *neuroeducation*, *brain, mind and education*, and *science of learning*), in which the term "neuroscience" alludes mostly to cognitive neuroscience (Howard-Jones et al., 2016) and it is under this lens that this research was conducted.

One challenge posed by this research is the definition of the researcher's philosophical position, especially when the object of study – learning – necessarily involve two different perspectives in its understanding: the understanding of learning from cognitive neuroscience, and that from education. As has been described in Chapter 2, a cognitive neuroscience perspective understands learning as a change in behaviour which involves the interplay of different mental resources and memory systems via modifications in brain structures and neuronal connectivity. However, the concept of education embraces a wider notion of learning as this is understood as being shaped by culture and values as well as explained by psychological and educational theories (Howard-Jones, 2008b). As educational neuroscience is still considered an emergent field and has not been free of criticism, it has been difficult to establish a balance in the way each science contributes to one another and efforts to provide a common explanatory framework are still a matter of debate. Figure 4.1 shows a modified diagram of an original model to describe the different levels that operate in cognitive neuroscience research (Morton & Frith, 1995) that shows how mind and brain interrelate in the study of cognition and how the causal connections are understood from a cognitive neuroscience perspective. The dotted arrows show the possibility of a bidirectional link that originates in the factor of behaviour with the possibility of influencing the mind and brain levels. This shows how behaviour can also give origin to changes at a brain level, i.e. novel environmental factors can affect behaviour and with that the intra-individual factors such as learning; brain structures are also modified as a product of this behaviour (Howard-Jones, 2008a).

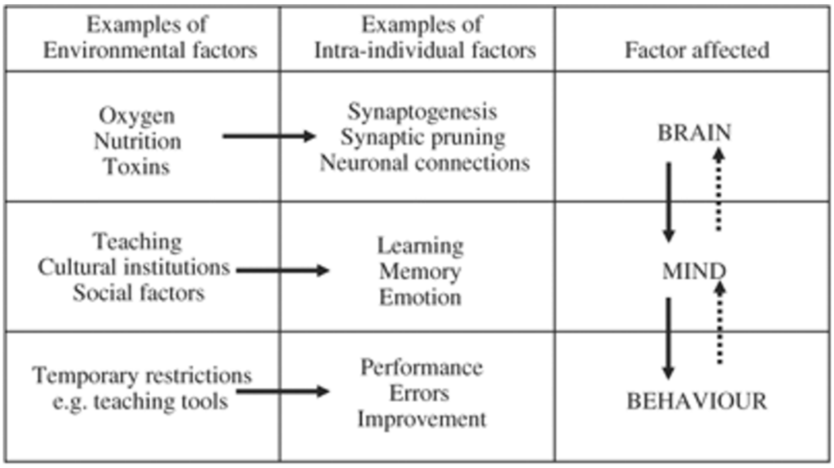


Figure 4.1. An adaptation of the model of Morton and Frith (1995) to represent cognitive neuroscience levels of description (Blakemore & Frith, 2005) and modified by Howard-Jones (2008a) to indicate causal inferences and the link between biology and behaviour that can be considered to travel both ways via the mind.

The issue of different explanatory frameworks for the concept of learning in the disciplines of education and neuroscience may complicate the way in which knowledge from one field is applied or transferred to the other (van der Meulen et al., 2015), as their concept does not come from the same framework and might simplify the understanding of key concepts. The explanatory framework for neuroscience understands behaviour as the end outcome of a chain of causal events that flow from the brain, passing through the mind until reaching behaviour (Cromby, 2007), but often it does not consider the reverse way, seeing the brain as the receiver of the actions of the different behaviours (Howard-Jones, 2010). Conversely, the framework for the educational field considers behaviour as a starting point for explanations, i.e. subjects can exert reasonable and intentional agency and behave within their natural, social and cultural environment (Bakhurst, 2008), and this will bring about learning. This gap between the understandings of neuronal activity in the brain and those of human cognition in daily behaviours needs to be bridged for the establishment of the field of educational neuroscience (Joldersma, 2018). This divide can be only reconciled via conceiving educational neuroscience as an interdisciplinary or transdisciplinary field (Ansari et al., 2012) with an explanatory framework that considers a bidirectional relationship between brain, mind and behaviour (Howard-Jones, 2010).

Arguments against this transdisciplinarity within the field of educational neuroscience represent a challenge for the bridging of these two sciences (Bowers, 2016; Bruer, 1997). Criticism lies in the reasoning that neuroscience is not strictly relevant to explain educational learning from a science perspective and that it has little to offer (Bruer, 1997) as compared with cognitive psychology, a field that has provided sufficient evidence for learning processes with powerful behavioural measures that seem more relevant than the neural measures provided by neuroscience (Bowers, 2016). The argument has been disputed by many who work in the field by incorporating evidence, theoretical frameworks and methodologies from both education and neuroscience to make progress in the transdisciplinarity of the field (Gabrieli, 2016; Han et al., 2019; Howard-Jones, Varma, et al., 2016). Despite efforts, a slow progress has been reached in establishing the field more solidly, mainly because of methodological conflicts that reflect the nature of each science (Turner, 2011). Thus, explanatory frameworks are needed and while the field progresses based on these frameworks, its ontology and epistemology would also be a matter of questioning.

Different models or frameworks have been proposed as a bridge between neuroscience and education establishing levels or layers of knowledge to pursue research in this field (Han et al., 2019; Howard-Jones, 2010; Tommerdahl, 2010). The need to extend the framework of brain-mind-behaviour to the social world has been represented in the model depicted in Figure 4.2, which also demonstrates the complexity of addressing all four areas in a single discipline (Howard-Jones, 2010). In this conceptual framework of levels of action proposed by Howard-Jones (2010), learning is represented as the interaction of two individuals (e.g. teacher-student or student-student), which suggests the complex interrelation between behaviour and neural processes in the educational field. The symbols around them represent communication (in various forms) with learning produced through the interplay of elements in all these levels. The arrows show the scope of different research pathways which are in turn related to different underlying epistemologies. This framework sheds light on the issues and potential pitfalls in the positioning of educational neuroscience when investigating educational matters from a cognitive neuroscience perspective.

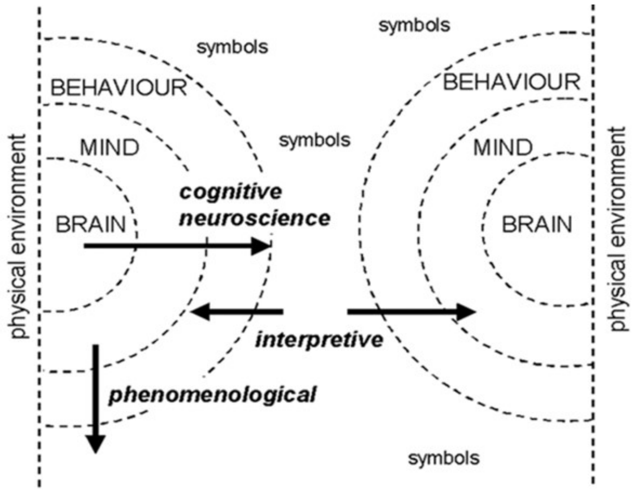


Figure 4.2. Levels of action conceptual framework proposal that includes brain-mind-behaviour model in interaction in the social environment (Howard-Jones, 2010).

Another model proposed for the study of educational neuroscience is that of Han and colleagues (2019) that also involves multiple layers of explanations (*Figure 4.3*) from both neuroscience and education to give account of how learning is produced. The goal is to combine the different understandings from these levels for informing educational practice. The incorporation of different methodologies, necessary for a transdisciplinary field as educational neuroscience, entails different levels of explanation that need to make sense to both educational and brain sciences (Ibid).

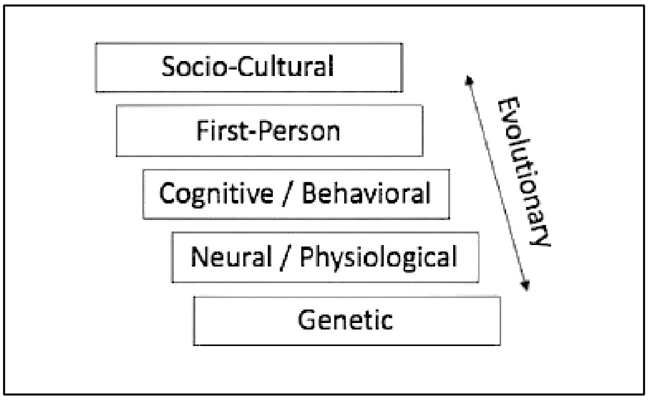


Figure 4.3. Model for understanding educational neuroscience research as a transdisciplinary field that incorporates different levels of explanation from neuroscience and education (Han et al., 2019).

These frameworks must face the challenge of associating the singularities of each of the levels/components that entail their own methodologies and approaches to research and are considered independent sciences. Indeed, the way in which one science may inform the other would benefit from the use of a common lexicon that does not exist because each field has dealt with their own understanding and terminology for referring to learning as either a biological or social phenomenon (Beauchamp & Beauchamp, 2013). Whichever the model adopted, it is worth noting that neuroscientific evidence and explanations should be used to complement sources of evidence about education that are more related to cultural and social world, instead of replacing them. Thus, neuroscientific findings should not be expected to a have direct application in pedagogy, but first should be translated into appropriate educational terms, for example in the design of educational resources.

There is no one single study that can address all levels/components of the mentioned frameworks at once. Complimentary studies are needed to address a research question from an educational neuroscience perspective. In this regard, Howard-Jones (2010) proposes three categories for studies in the field of educational neuroscience: *scientific studies*, which are intended to reveal new knowledge from a mind-brain perspective with a view on educational issues; *bridging studies*, which are aimed at examining the potential relevance for education of conceptualisations about learning that contain a neuroeducational view; and, *practice-based studies*, whose aim is to develop an understanding and transfer of concepts that encompass a neuroeducational view and that have been originated in the two types of studies mentioned before. However, it is proposed that these studies are not conducted in isolation and that they should inform each other of the sciences. These different types of study are as well associated with distinctive sources of evidence that Howard-Jones (Ibid) depicts as biological, social and experiential that will serve the purpose of understanding learning.

Horvath et al. (2017) identified four goals on which a science of learning should focus in order to translate laboratory findings into real-world settings. First, consolidating foundational principles about learning that stem from different disciplines. Second, establishing a correspondence of learning principles with known classroom practices to serve as an explanation for both new and current practices. Third, developing a stage of close collaboration between educators and researchers to develop learning strategies based on scientific findings. And finally, researching in the reverse order, i.e. from the classroom to the laboratory, to address issues related to causal mechanisms involved in human learning.

The present research is an attempt to draw on neuroscientific and psychological concepts to develop a behavioural hypothesis regarding a specific type of learning, one which considers that the tracking and action over cues might influence the processes of attention and memory when included in a computer-based game-like task, but with an educational, rather than a purely entertaining, purpose. In doing so, understandings of learning from an educational perspective are necessary as well as insights from cognitive neuroscience to propose such possibility of learning. As an attempt at contributing to the development of the field, this research addresses the first of the four goals proposed by Horvath et al. (2017) – to consolidate data from diverse disciplines in order to generate foundational learning principles (which could then be associated with current classroom practice, as stated by the second goal). Hence, for the current research, laboratory research represents an initial step in investigating the underlying processes of learning through computer games. However, the experiments conducted do not address the interaction of these cognitive processes directly in the social world as there is the need for establishing the foundations of learning (if possible). The use of laboratory experiments to shed light on issues of the social world might seem contradictory because the nature of experimental research depends on the control of external variables, which in the real world are numerous. With scientific knowledge obtained in this type of research, a further study would involve researching behavioural processes of this learning in more natural and collective and less controlled environments and address the missing space between the two subjects in Figure 4.2. Therefore, it will subsequently be necessary to go beyond experiments and investigate how these learning behaviours develop in real contexts with numerous variables and inform classroom practice

(Blakemore & Frith, 2005; Horvath et al., 2017; Howard-Jones, 2010). However, this extension is not investigated in the present research project.

4.2 Philosophical issues of a transdisciplinary field

The issues of a transdisciplinary field in the previous section have collaborated with the idea of incompatibility of the interaction between education and neuroscience, and also added to the difficulty in adopting a philosophical paradigm to this science (Clark, 2015). The lack of actual philosophical narrative in the intersection of education and neuroscience as well as the need for philosophers to address these issues has been pointed by Joldersma (2018). In this matter, philosophers – as epistemic experts – may offer insight on how research should be conducted in the field (Clark, 2015).

Roy Bhaskar's critical realism emerges as a closer philosophical underpinning, though still partial, to approach the field of educational neuroscience ontologically. This approach arises as an alternative paradigm to the restrictions posed by the claims of the objectivity and certitude of positivism (Delanty & Strydom, 2003). In a realist perspective, there is a real world that exists independent of knowledge and beliefs about it. The knowledge and modification of this world depends on our possibilities of acquiring knowledge (Bhaskar, 1979). Bhaskar defined reality as "structured, differentiated and changing" (1989, p. 2) and science can define the underlying structures required to generate discourses and events (phenomena) in a social world.

The aims in educational neuroscience research seem compatible with the views of critical realism. Firstly, a critical realist perspective assumes that there are biological structures that allow learning to occur. Although these structures across individuals might share the same function and common underlying components, they might act in a differentiated way, i.e. learning does not occur in the same exact way in the same set of structures across all individuals because of individual differences. Also, there is a social world that allows the emergence and bidirectional interaction of such structures through interaction of the individuals. This interaction of structures with and within the social world generates changes in them. In other words, the structures that allow us to perceive and understand the social world are modified by our experience of it. Perhaps, if we understand such structures through theory and research, it will be possible to understand, and indeed alter, the social world. However, it is also important to understand how structures interact with this world. In this sense, evidence from cognitive neuroscience may influence our understanding of learning processes that we assume exists and we can discuss, but we should remember its partial nature and that the real-world learning processes themselves entail a structure that is differentiated and in constant change (Bhaskar, 1989).

The issue of positioning research that encompasses two apparently distant fields is a difficult one and possibly this study only makes partial inroads at this stage. The findings that emerge from the proposed research must be considered a contribution to new conceptualisations of a philosophy that includes the concept of learning from an educational neuroscience approach. However, in the meantime, it is necessary to be cautious and careful when making claims and using concepts arising from the link between neuroscience and education, not least since concepts around learning and the language used to describe them might differ greatly in these two fields.

With the problem of establishing the philosophical stance for educational neuroscience from which to approach the research, an epistemological stance seems to follow the same problematic issue. While education addresses the question of 'what we know' from an underlying epistemology based on subjective and holistic perspectives, the sciences rely on experience as the principal source of knowledge – empiricism – approaching knowledge from more analytic and objective perspectives (Samuels, 2009). Samuels (2009) states that reconciling these positions is unrealistic, but recommends instead a transdisciplinary approach, inserting the different epistemologies into a collaborative framework that allows the creation of knowledge in this field. Establishing epistemological grounds is an initial step in the development of the discipline to avoid the emergence of pseudo-sciences. However, it is also important to develop new conceptualisations around learning and knowledge which may further emerge through the possibilities granted by technological advances to expand our potential of observing and studying a phenomenon. Therefore, rather than eternally discussing about the incommensurability of the education and neuroscience association, the focus should be placed on conducting research to contribute outcomes valued across disciplines (Varma et al., 2008).

Whereas educational neuroscience can be understood under a critical realist perspective in terms of its understanding of learning as a human biological activity in a social context, the different types of studies that can be conducted to understand learning from this perspective will make recourse to different approaches and traditions to research. The current experimental research has been framed under a postpositivist approach in the understanding that research is fallible because all observations of a reality that is independent of our idea of it are biased by our own possibilities of observation as researchers (Popper, 1969). Therefore, all theory built upon the observation of reality may be subject to revision. Indeed, this is how science has generated knowledge built on previous findings, by iteratively modifying previous claims (Phillips & Burbules, 2000). In this sense, knowledge is not static but is constantly evolving in synergy with our understanding.

A postpositivist stance seems to partially fit in this composite field. Bhaskar's concept of epistemic fallacy alludes to the reduction of 'what we know' to 'what it is' and it arises from epistemology and ontology, respectively (Alvesson & Sköldberg, 2009). It is a fallacy because we cannot answer the question of whether some particular thing or event exists with the knowledge we have about it. The experimental approach used in this research will answer the question of 'what we know' (epistemology) about video game-based learning. The ontology ('what it is') of learning requires multiple inputs from different sources in order to be able to establish knowledge under the umbrella of critical realism. For critical realism, it is the social world that generates science, but the structures and mechanisms that science can determine exist before they are discovered and exist independently of this (Bhaskar, 1989). Therefore, reality can be interpreted by the actual possibility of detecting, perceiving and observing it. Thus, the knowledge that every science may attain will be facilitated by their lexicon, theories and even available technology. But as these emerge from the observation of reality, theories will not be permanent and will need to be under constant revision.

The scope of this research is restricted to the generation of scientific knowledge – which will itself be subject of constant revision – through behavioural experimentation but keeping in mind the translation of this knowledge into educational practice. In terms of the four steps suggested by (Horvath et al., 2017), this research is just the first link in that chain. It is a starting point on which to further build our understanding of these realities.

4.3 Methodology

To address the research question,

RQ_$_{main}$ What is the influence of the movement of learning stimuli, tracked as part of an educational video game-like task, on the declarative memory of their properties, as measured by accuracy and speed of recall?,

The present research is divided into five experiments. All of them followed an experimental, pretest-posttest, within-participants design to test the hypotheses. Two stages within each experiment are identified: assessment, which corresponds to the application of the assessment tasks (pretest and posttest), and game play, which corresponds to the session in which participants played the video game-like task. A detailed organisation of the experiments is provided in section 4.3.6.

The dependent variable – learning – was measured in two levels, accuracy and response time (RT), which were defined by the difference between pre- and post-test. The two conditions of game play were the levels of the independent variable, which are related to the presence or absence of the action element in the game-like task represented by objects in motion. Conditions were labelled 'motion**'** and 'static'.

This chapter contains a general description of the methods used in the research. However, more details, particular to each one of the experiments, will be described as the studies are presented (Phase 1 for Experiments 1 and 2; Phase 2 for Experiments 3, 4, and 5).

4.3.1 Sampling

This research used a non-probability convenience sampling based on students at a university in England. Participants of the different experiments were students of different programmes and backgrounds. It was relevant for the studies to sample people in education and with diverse backgrounds and interests (study programs) to make it representative of other educational contexts. A sample from university students might be considered a limited group regardless of the differences encountered among individuals within this group. This perceived homogeneity was useful as identification with a student population that may share common aims, such as pursuing academic development to enhance their prospects in the workforce. However, students from a UK university implied a variety of nationalities and ethnicities that enriched the sample as they made it more diverse within the specificity.

Participation of students of all ages was accepted and there was no special requirement concerning the type of player (avid or no player) or game task they would play. Participants were made aware about the nature of the study prior to partaking but not of the content of the game-like task in order to avoid preparation and to foster participation free of pre-established conditions. Due to the use of a snowballing technique for recruitment, participants were encouraged not to disclose the content of the gaming task when engaging friends into the study, which they rightly did.

The recruitment process was via university emails and posters (Appendix III). The snowballing technique also allowed to reach more participants. However, at the onset of new General Data Protection Regulation (GDPR), the recruitment was reduced to posters around the university buildings, but no direct messages were sent to address potential participants as the need for consent prior to receiving information was now in place. Another recruitment method adopted was through general information in the course units, and a very personalised way of approaching participants emerged as part of the process. The participation did not offer credits nor money incentive. Educational material relative to one of the units of the master's programme in education was offered to those who took part in the studies. Participants who consented to take part were sent more information on the study and the tasks involved and were invited to book an appointment via an online scheduling software.

An *a priori* power analysis was not conducted as there was no reference to similar research with video games conducted in laboratory settings with a purpose-built task and measuring learning. Generally, studies tend to use commercial games and they mostly involve training and cross-sectional designs. Additionally, there was not enough financial capacity to recruit larger sample sizes for several experiments. However, *post-hoc* and a *sensitivity* analyses were conducted using G*Power 3.1 to estimate a) the power (1-ß) of the study as a function of the obtained alpha, effect size and sample size; and b) the population effect size as a function of the obtained alpha, a desirable 1-ß = 0.80, and the current sample size. The post-hoc analysis was conducted to understand the power of the study with the possibilities of accessing the sample size used in the experiments. The sensitivity analysis was conducted to determine the effect size that can be expected with higher power (1-ß = 0.80) and the current sample size (Appendix VIII).

A total of 155 participants took part in the experiments (Experiment 1: N = 20; Experiment 2: N = 16; Experiment 3: N = 19; Experiment 4: N = 49; Experiment 5: N = 51). The number of participants differed across studies which conformed to the possibilities of obtaining participation in the context described. The use of students as experimental participants is widely represented in laboratory studies and has sometimes been criticised as it seems to pose a problem for the validity and generalisability of findings (Druckman & Kam, 2011). However, this study – which used students as participants – intended to research learning through computer game-like tasks which has a potential to be extended to educational contexts, such as higher education institutions. The reason for using university students is first, to work with people within an educational context and second, that these people are a heterogeneous group in terms of age and background. Hanel and Vione (2016) demonstrated that students do present levels of variability as much as the general public in terms of attitudes, making them an eligible sampling source for generalising findings. There was also a practical argument behind the choice of students for laboratory studies related to the availability and easy access it entails compared to other educational settings such as schools.

4.3.2 Measures

This research investigates learning as measured by response time (RT) and accuracy of the responses. Speed and accuracy have been two measures of performance used in cognitive research, typically expressed by response (reaction) time and the proportion of errors (PE) (Vandierendonck, 2018). Memory processes are at the basis of learning, and measures of RT and accuracy have been used in cognitive research in human memory (Kahana & Loftus, 1999). While studies in perceptual learning are more inclined to measuring improvements on accuracy, research in cognitive skills look for improvements in response times (Liu & Watanabe, 2012).

Studies in memory have traditionally used measures of accuracy. With the advent of computational science in the mid-1970s, the use of response time in psychological research became a preference and a standard, given the possibilities of measuring real-time responses with computers (Kahana & Loftus, 1999). Despite the ease in their capture, RT measures pose a main challenge associated with the many factors that can influence such measures, e.g. RTs that are high may imply slow processing speed in subjects, or that they are extremely careful when responding (Kyllonen & Zu, 2016). When the two measures are interpreted in association, it leads to a potential speculation of their meaning depending on the association. For example, subjects may show faster RTs and correct answers which may be interpreted as a lucky guess, but if they take time in answering correctly, then it could be interpreted as they might need incentives. A bigger problem arises with incorrect answers, which expands possible interpretations to lack of knowledge, not dedicating much time to the question or being confused and stopping answering (Kyllonen & Zu, 2016). In any case, the interplay between RTs and accuracy of responses observes the phenomenon of speed-accuracy trade-off (SAT), in which more errors are generated by faster responses (Liu & Watanabe, 2012).

Efforts to theorise an integration of accuracy and speed have yielded three most commonly known measures oriented to balance these two elements and address the speed-accuracy trade-off issue: *inverse efficiency score* (IES) (Townsend & Ashby, 1978); *rate correct score* (RCS) (Woltz & Was, 2006), and *linear integrated speed-accuracy* (LISAS) (Vandierendonck, 2017). In memory research, there are multiple processes and types of information involved that can be better informed by an integrated measure or pattern of RT and accuracy (Kahana & Loftus, 1999). However, these combined measures have not been widely used by researchers as there is still no agreement on the accuracy of a combined measure (Vandierendonck, 2017).

Recommendations for a combined measure of speed and accuracy are related to the difference between the scales involved in RT and accuracy. Response time corresponds to a precise millisecond (or second) scale whereas accuracy is a more coarse measure based on correct/incorrect scoring or by the degree of errors produced. This makes RT a more reliable measure than PE and more used in practice. However, if the theory points to an effect in both aspects of measurement, then just choosing RT because of its reliability would be arguable (Vandierendonck, 2018). It is important to consider both measures in order to provide a fuller interpretation of a cognitive phenomenon. Whereas there is no one integrated measure that has been deemed as the solution for the interpretation of measures of performance, the usefulness of combined speed-accuracy measures is related to methodological and theoretical considerations, such as the type of experimental task involved as well as the instructions given to participants. For example, if participants are told to give as many possible answers in a given time, this will certainly affect their performance as they would be faster but possibly with more errors on their account. Similarly, different experimental tasks explore different cognitive skills in which performance is better portrayed either by the use of RT or accuracy or responses individually.

In this sense, Vandierendonck (2018) describes three possible scenarios to consider the use of an integrated measure based on this different relationship between RT and accuracy. First, it is possible that RT and accuracy cannot be meaningfully combined as their origins are different. An example of this can be illustrated through tasks that involve categorisation, because RT becomes faster with task progression, in which case RTs account for earned confidence in the task, demonstrating acquired knowledge; meanwhile, low accuracy rates imply not knowing the categorisation rule. Second, it could be that theory supports predictions for only one of the aspects of performance and not the other, making the combined measure irrelevant for the interpretation of results. Finally, a third case poses the theoretical relevance of both speed and accuracy to interpret the cognitive phenomenon. However, the use of a combined measure would not be appropriate if the effects produced in speed and accuracy are opposite or expected to be as such. But if the effects are strong for both aspects of performance, then only theory could help disambiguate the issue (Vandierendonck, 2018). Therefore, a combined measure of speed and accuracy seems useful when the effects of RT and accuracy are in the same direction, but it does not seem a straightforward mechanism.

For this research, the measures of RT and accuracy are considered for both the game play and the assessment stages. Working with computerised tasks facilitates the accurate recording of measurements. These factors of performance have been treated separately and no integrated measure was considered for the analysis, based on the principle that both reflect different origins and the tasks used fall within the categorisation nature. Therefore, speed is expected to show learning via faster recognition, and accuracy reflects being able to show knowledge of the categorisation rule at the beginning and memory recall as trials progress during the game play stage. At the assessment stage, RT reflects faster recognition which implies faster retrieval from memory; accuracy is in line with this, but it is also expected to be affected by confusion or simply not knowing the answer.

4.3.3 Instruments and materials

The present research involved the use of a purpose-built game-like task to investigate the influence of the feature of motion tracking in declarative learning. Therefore, the use of video game design principles was central to this research. This section describes the instruments used in this research with detail on the process of designing and coding the two gaming tasks as well as the assessment task and the learning corpora.

4.3.3.1 Game and play

The concepts of *play* and *game* seem to be intrinsically related. The first time these concepts were addressed distinctively and scientifically was through *The Homo Ludens* by Huizinga (1938), which defines and describes the influence of play from a cultural and historical perspective (Anchor, 1978). The use of two different words 'play' and 'game' captures two distinct understandings. While *play* comes from the Greek *paidia*, meaning 'free play', *game* finds its origin in *ludus*, which implies a pursuit of goals that is challenging and structured by rules (Caillois, 2001). Playing has been generally characterised as a free activity, that is unproductive but at the same time regulated and with elements that make it a believable activity (Ibid.). The concepts of game and play and how they interrelate have been addressed by philosophers, sociologists, psychologists and game designers as well. Their relationship has mainly been understood in two general ways: a) games as a subset of play and play, i.e. activities that are normally called play and do not constitute a game because they are less organised; and b) play as an element of games, among the many other elements that games have, such as rules, steps, etc. (Salen & Zimmerman, 2004). The latter distinction is the one that this research adopted as games in this context are understood to provide the possibility of playing but also of learning.

The understanding of game in this research follows what most definitions suggest, a system in which players face challenges they need to overcome in order to pursuit the goals established by the game, while acknowledging a set of rules, objects and obstacles presented to challenge the pursuit of such goals (Juul, 2005). Therefore, game designers need to consider certain basic elements to be included in order to create a game. Furthermore, the design of such systems needs to orchestrate those elements in a mechanics that generates enjoyment and fun for the players and makes them willing to play a game, i.e. to motivate them. Malone and Lepper (1987) argued that some elements in video games increased both internal (e.g. challenge, control and intellectual curiosity) and interpersonal (e.g. competition, cooperation) motivations. The use of challenge (a specific type of difficulty that requires skill and effort to be solved) in video games can foster motivation and enjoyment through the generation of the feeling of competence when a non-trivial challenge is overcome, or simply because the outcome of a challenge is in itself uncertain and triggers interest and arousal (Malone, 1981). Therefore, the use of challenges should be at the centre of a gaming experience as they are sources of motivation and the enjoyment of games (Deterding et al., 2013).

4.3.3.2 Game design

Although designing might be considered a creative and free task, it normally follows a process that is not a defined and structured one, but contains some common steps or elements that help the design to achieve its final stages in a smooth way. Game design has emerged as a science that support guidelines to put elements together in a unique way in order to obtain the desirable effects of what a game implies. The evolution of games into the digital world has increased the interest for game design in order to create a likeable product but also to further understand the reasons for people playing video games as well as why some games seem to find higher popularity than others (Salen & Zimmerman, 2004). Today we can see implemented the newest technologies in video game play such as virtual reality or kinetic-based games with high-definition graphics and very close-to reality worlds. However, in the past, simple games such as Pong with none of the high-tech elements present in today's games still enjoys a great popularity, due to the core elements present in these games. In the case of Pong, it is an engaging game and simple to play that incites the challenge to win (Salen & Zimmerman, 2004). Hence, technology could be in the high end, but it is the design around the core elements that seem to carry the weight of a game's success.

Processes of design are unique to the element being designed. However, most design processes would follow a series of common steps that do not follow an order necessarily but that are iterative in nature (Preece et al., 2011). From an initial concept, passing through its clarification, validation and development to designing prototypes and conducting testing and trialling phases, to its reevaluation; all of these steps are common to the design process. The development of a game involves the inclusion of specific features and steps that need to coexist and coordinate congruently. Hence, game design is the essential manner to make sense of the elements related to the game (Mora et al., 2015).

Game design has emerged as a trend that has established certain guidelines and frameworks to put elements together in a unique way in order to obtain the desirable effects of what a game means. The most well-known framework used for game design is the MDA (Hunicke et al., 2004) which integrates the elements of video games under three categories: *mechanics*, i.e. the rules that specify the actions that are possible in a game, generally in the form of algorithms; *dynamics*, which refers to the interaction between player and the mechanics (rules) in run time; and finally, *aesthetics* which alludes to the – ideally desirable – experience that emerges from the interaction between dynamics and mechanics of the game.

The construction of the game-like task for this research followed an iterative design process, i.e., a design process based on the user experience of game play with an emphasis on prototyping the game features and dynamics and playtesting them in order to make more permanent decisions for the final version (Preece et al., 2011; Salen & Zimmerman, 2004). The initial idea emerged from the need to create a gamified laboratory task that could emulate as closely as possible the features of computer games that make them engaging for players but include learning content in a playful manner. Following the initial sketches and amendments to the procedural steps, it was coded and tested as it was being developed.

4.3.3.3 Game components and features

Most games must have certain formal elements around their design and construction. They can be structural elements such as the objective, the rules and procedures, the type of conflict, the outcome, the number of players; or else refer to dramatic elements such as the type of challenge, whether the rules allow a sense of play and the story/setting or characters involved (Fullerton, 2019; Salen & Zimmerman, 2004).

The 1980s was an important period for the video game industry, as computer games became a popular entertainment amongst children and young adults in most of the Western world. Decades later, video games have not just increased their popularity but also experienced a remarkable enhancement of their technological features, making them increasingly more realistic and engaging. Today, we are witnessing the onset of rapidly permeating new and portable devices that allow for virtual reality games to soon be the next stage. However, certain features of video games such as fast-paced action, rapid schedules of reward, and most often a degree of competitiveness, have remained unchanged. Studies have suggested further characteristics that contribute to the engagement of video games, such as *interactivity*, through feedback cycles that enable players to assess their performance as it unfolds during a game (Renkl & Atkinson, 2007; Ritterfeld et al., 2009; Weber et al., 2014); *feedback* received in order to progress through levels of performance (Burgers et al., 2015; Lieberman, 2006); *identity*, including interactions with other players combined with the creating of a personal identity (avatar) (Blascovich & Bailenson, 2011; Murphy, 2004); and *immersion* in an environment (e.g. high-resolution graphics and virtual reality) giving players a feeling of a pleasant state of flow (Csikszentmihalyi, 1990; Tamborini & Skalski, 2012). Different combinations of these features and functions, including competition, uncertainty, and action have given entertainment video games a special appeal that keeps players engaged in the game (Kirriemuir & McFarlane, 2004).

The elements that were considered into the design of the games used in this doctoral research are drawn from the literature on game design with a consideration in mind that not all of the elements could be included, as the purpose of the study is to inquire of a particular element which is the motion of objects. Nevertheless, the element of *challenge* was interweaved into the game design following some of the guidelines for assuring a pleasurable experience of competence (Deterding, 2015) and avoiding frustration leading to disengagement and lack of motivation.

The provision of *feedback* is another feature relevant not only to entertainment video games but also to their educational counterpart. Feedback for video games can adopt different formats; most commonly, games provide a direct indication of success by increasing scores, adding lives, or any other celebratory symbol with the meaning of triumph. Feedback has not only to be relevant and celebratory but also timely (Bavelier et al., 2011). As feedback is part of reinforcement learning it allows for adjusting the prediction error when the feedback is negative or celebrating when it is exceeded. The role of feedback on performance is less conclusive than the effects of feedback on motivation (Garris et al., 2002).

Nevertheless, the interruption produced by the provision of feedback may attempt against the *flow* of the game, which is another relevant feature for game play to produce that feeling of immersion that Csikszentmihalyi (1990) refers to as 'being in another world' and that leads to a feeling of engagement in game play (Garris et al., 2002). It is difficult to handle the concept of flow in a gamified learning experimental task that needs timely feedback, i.e. after each response is marked, to promote both learning (= enhanced performance) and engagement with the task. However, if these interruptions occur regularly after some time, players become used to the dynamics, i.e. the interaction between the player and the mechanics of the game becomes their understanding of the game and the sense of flow (Csikszentmihalyi, 1990) would take place.

Some elements that are not included in the game-like task used in this research are related to the possibility of progressing to different stages, a world of fantasy provided by a narrative and the interaction with characters or creating avatars. None of these elements were considered relevant for the present research as they also represented more variables to control for. Nevertheless, the gaming tasks were designed with the possibility of continuous growth in case it was needed.

4.3.3.4 Coding

Video games are pieces of software that simulate a rule-based behaviour intended for a specific purpose and written in the form of code. A code is a set of structured and ordered rules and procedures that contains a set of potential outcomes which would trigger depending on the interaction with the player's decisions. These rules need to be written, i.e. coded into particular programming languages that depend on the software being used. The activity of coding is a writing one, but it differs from writing prose, in the sense there are restrictions and limitations to the 'freedom of speech', as rules for syntax and grammar and spelling are much stricter and are unambiguous. Additionally, the understanding of the configuration of the world is different. When writing prose, we are in the world and we describe it; in coding we write the commands to create the world and the possibilities of interaction with it. A code needs to 'narrate' a configuration of the world intended to be represented (Ian Bogost on Fullerton, 2019).

The code needs to activate the quality of procedurality (Murray, 1998) that it entails so that the computer can execute the intended rule-based behaviours. This can only be achieved through correct application of the rules of syntax and spelling. Additionally, the limitations of the game play environment also need consideration when writing these procedures, for example, the type of devices that may be used to provide input to the game as well as the way to display the output are essential for a correct recall of the procedures. The procedures allow the interaction between the player and the game via loops, which are established forms of syntax that work with the players' input in order to give the game a sequence.

The arduous endeavour of coding involved in the design of the gaming tasks for this research aimed to simulate objects in motion on the screen to follow the objective of being chased and captured by the player according to instructions provided. The two computer games and the testing task used in this research project were coded by the researcher with guidance from the supervisor to generate a computer-game-like task that allowed for smooth game play and at the same time recorded information on its usage (see codes for Game-like task 1 in Appendix X; Game-like task 2 in Appendix XI; Game-like task 2(2P) in Appendix XII; and Tester in Appendix XIII). Visual Basic was used as programming software and although it is not widely used for programming video games, it was chosen for its user-friendly interface for design and the possibilities of exporting information recorded.

4.3.3.5 Video game-like tasks

Two computer video game-like tasks were designed and coded for this research following principles of game design and evidence from cognitive science in the area of attention, memory and visual motion tracking. The games were developed as a laboratory task to enable adults to learn a specific content – prime numbers – considering the feature of objects in motion that needed tracking as part of the game design. Additionally, the games include elements to foster engagement and competition and maintained a sensitive level regarding players' individual differences, i.e. providing a level of challenge proportional to the skill demonstrated while playing.

Game-like task 1 was the task used in Experimental Phase 1 that comprised the first two experiments conducted to understand whether visually tracking stimuli had an effect in the recall of their semantic properties (i.e. their meaning). This phase was also used to provide a further understanding of the ecological validity of the game task given its early design to resemble the features and mechanics of entertainment video games while preserving its capacity of being a laboratory instrument. Game-like task 2 – used in the three experiments of Experimental Phase 2 – was attempted to include more real-like computer game elements but preserving the simplicity of an experimental task that allowed the study of the particular feature of objects in motion and their effect on declarative memory. Both game-like tasks followed a similar dynamic which corresponded with the variables to be studied, i.e., they involved objects with semantic information to be learned either in a static or motion fashion.

Game-like task 1

The gaming task was designed with the aim of testing whether the visual tracking nature embedded in action games could be replicated in a simple game-like task for learning. As the game was also a task to serve a laboratory experiment, the emphasis was placed on designing a learning task that operated and felt like a real game in order to maintain an appropriate level of ecological validity. Therefore, a combination of design principles was embedded into the theoretical principles of motion tracking in the creation of the game.

Fullerton (2019) identifies ten possible objectives of games which define the main task players need to accomplish while playing according to the rules of the game. On Game-like task 1, players' actions fall between the concepts of *capture* and *chase*, i.e. players need to catch or obtain something while time is available and the trial is still on and this action of catching involves the chasing of such element due to its motion leading to a constant change of locations. Most video games have been designed around some common elements concerning the mechanics of games, their visual aesthetic design, an incentive system that promotes engagement and time on task, among other more flexible elements such as narrative design and sounds (Plass et al., 2015).

Game-like task 1 was built around a simple graphic environment with a single box containing numbers that appeared one by one. Among such numbers there were prime numbers which were the ones to be 'captured' (identified) by the player in order to win points. The gaming task was built in two separate versions which represented the two experimental conditions (motion and static) (*Figure 4.4*). In the motion version, the box containing the number moved around the screen in a random trajectory while the number in the box changed; players had to click on the number when they thought it was a prime and then received feedback. In the static condition, there was also a box with changing numbers, but this was placed at the centre of the screen and did not move; when players identified a number that was prime, they clicked on the button labelled SELECT using the mouse and then received feedback. Each version of the game-like task contained a modifiable number of trials, each one featuring a set of four numbers among which only one is a prime.

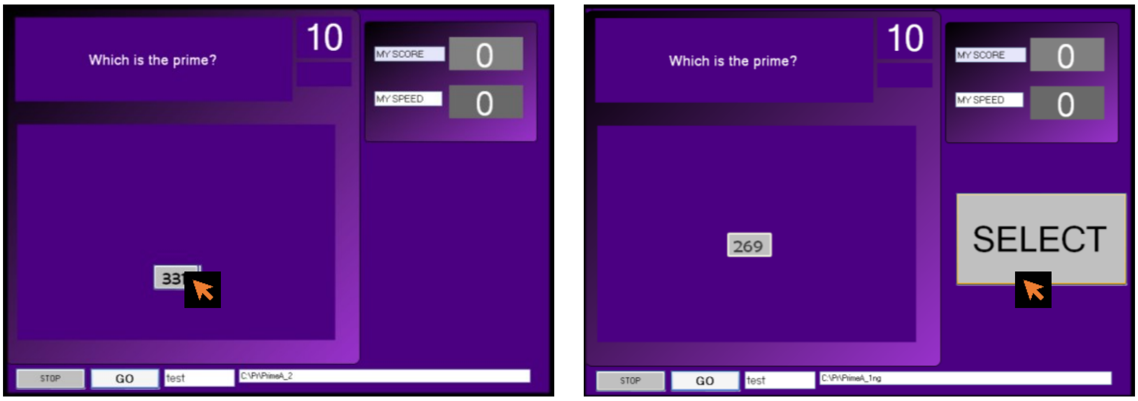


Figure 4.4. Game-like task 1: The screen on the left shows the motion version a box moving around the screen containing changing numbers; the player uses the mouse to chase and click on the number which is a prime. The screen on the right shows the static version of the game in which the box containing the number is centred and the player presses the button SELECT when identifies one number that is a prime. Each correct response gets 10 points.

Since the purpose of the game-like task was to promote declarative learning, all types of trials displayed distinct visual feedback depending on the type of response (correct or incorrect). This feedback was part of the game mechanics, like the one used in most games either educational or for entertainment to mark the player’s success or failure (Kinzer et al., 2012). Incentives in the form of scores are part of what Kinzer et al. call *informative feedback* (2012), which allows gamers to know they have hit the correct response. To learn more about the result obtained (in case of incorrect answers), a more elaborative feedback (Ibid) was provided through a motivational message confirming the correct answer or showing the exemplar factors (e.g. 273 = 21 x 13) of the chosen number, demonstrating it is not a prime (*Figure 4.5*). The feedback provided aligned with the purpose of learning within the game-like task as it would enable players to process their answers (i.e. correct them if they were wrong or ratify them if they were right), leading to an update of the mental representation of the information being processed.

Feedback represents a challenge in video game design as it might interfere with the flow of the game. One possible reason for educational games not being as popular as their non-educational counterparts is that they often emulate the mechanics of a set of drills in which feedback is absolutely necessary for learning (Deterding, 2015). The need for feedback is essential but needs to be embedded in an almost seamless way as part of the game dynamics. However, although necessary, feedback was not a primary goal of this game-like task at this stage as it was the development of the static/motion features to achieve the learning goal. Therefore, despite not being flawless, this way of providing feedback was a first attempt to make it promptly and with a minimum interference to the flow of the gaming task.

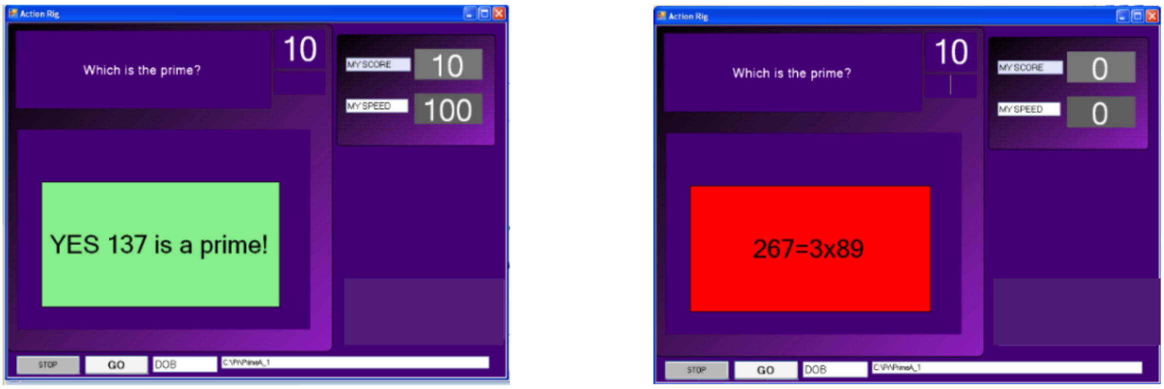


Figure 4.5. Game-like task 1 feedback screens after correct and incorrect responses. For correct responses, a green screen confirming the choice appears. For incorrect answers, a red screen containing the reason (in multiplication form) is given.

A typical trial in Game-like task 1 is shown for the static (*Figure 4.6*) and the motion (*Figure 4.7*) gaming tasks. First, there is a box with a number inside, which is either static or moving under the question: *Which is the prime number?* In the motion condition, players must click on the moving box when they see a prime number, while they need to press a button labelled SELECT on the side of the screen when playing in the static condition appears. The corresponding feedback window appears after each answer is marked and coloured according to the type of response. When no answer is marked, it goes to the next trial without any feedback. The scoreboard displays the points earned for correct responses on the upper right corner.

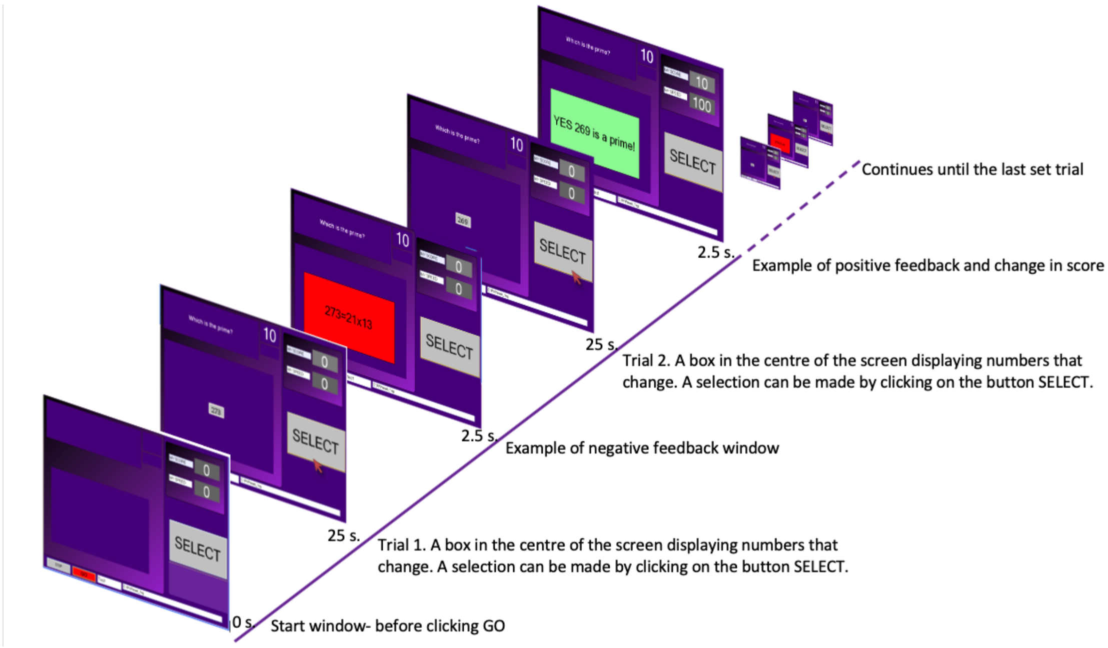


Figure 4.6. Game-like task 1 sequence screenshots for the static version. Players click on the SELECT button when they identify a prime number from the centre box. A feedback window after each response appears for 2.5 seconds. When no response is marked, it goes to the next trial after 25 seconds have passed. The scoreboard is updated.

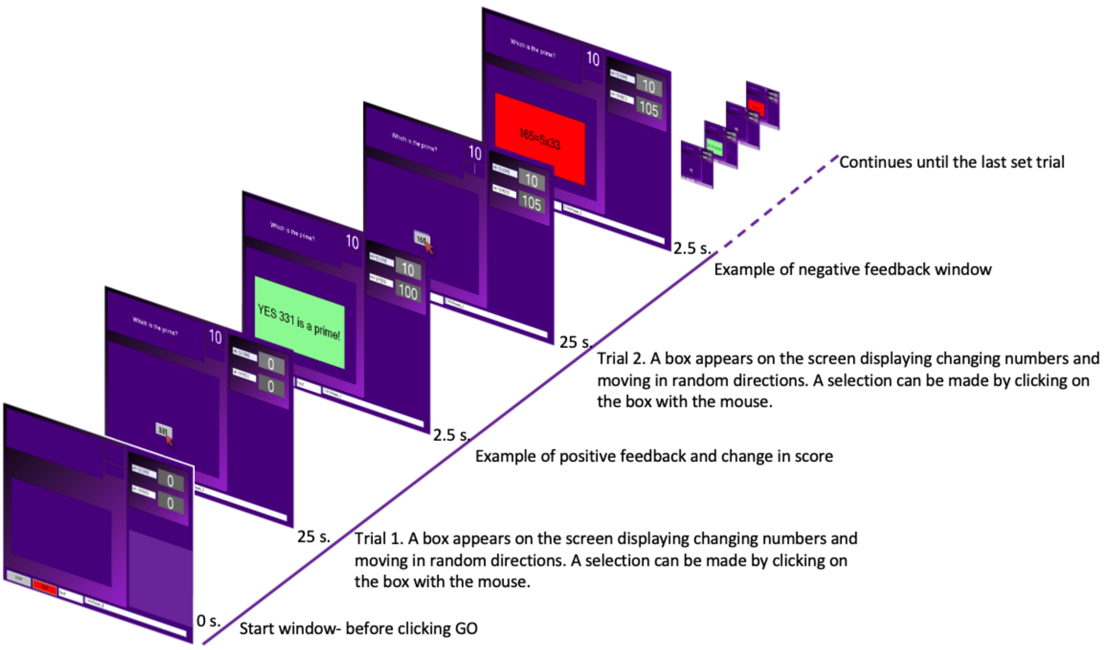


Figure 4.7. Game-like task 1 sequence screenshots for the motion version. Players click on the centre box when they identify a prime number. A feedback window after each response appears for 2.5 seconds. When no response is marked, it goes to the next trial after 25 seconds have passed. The scoreboard is updated.

In order to balance the challenge in relation to the player's perceived skill for playing the game, Game-like task 1 also included adaptive features involving the changing speed of motion and time the stimuli is shown on screen. These parameters were varied according to the player's response to the task, i.e. the gaming task learns from the types of responses and ways of responding and adapts accordingly. This manipulation of paramenters reflects the capacity of Game-like task 1 for eliciting information on the identification of targets irrespective of the difficulty posed by challenging trials adjusted to the players' specific performance. This adaptive design was aimed at maintaining a level of engagement and achievement in players which made them less likely to abandon the gaming task due to discouragement (Deterding, 2015).

Figure 4.8 depicts the flow of this adaptive feature which was based on the type of response or attempt of response given by players, i.e. whether they hit or missed the targets while playing. During the game task, players could either hit (click) the box with the number or miss the chance (click outside the box). If they hit, the number moved progressively faster in the following trial, irrespective of the response (correct/incorrect). This assumed a skilful player profile. If missed, the motion speed diminished in the following trial, assuming reduced video gaming skills. However, the time of display on the screen varied according to players' type of response. If the response was correct, the time of exposure was shorter but longer if the response was incorrect, regardless of the player's behaviour (hit or miss). Incorrect responses here assumed a player that needs more time to think about the answer while looking at the number on screen. Table 4.1 shows the interpretation for each behaviour a player had while playing game-like task 1.

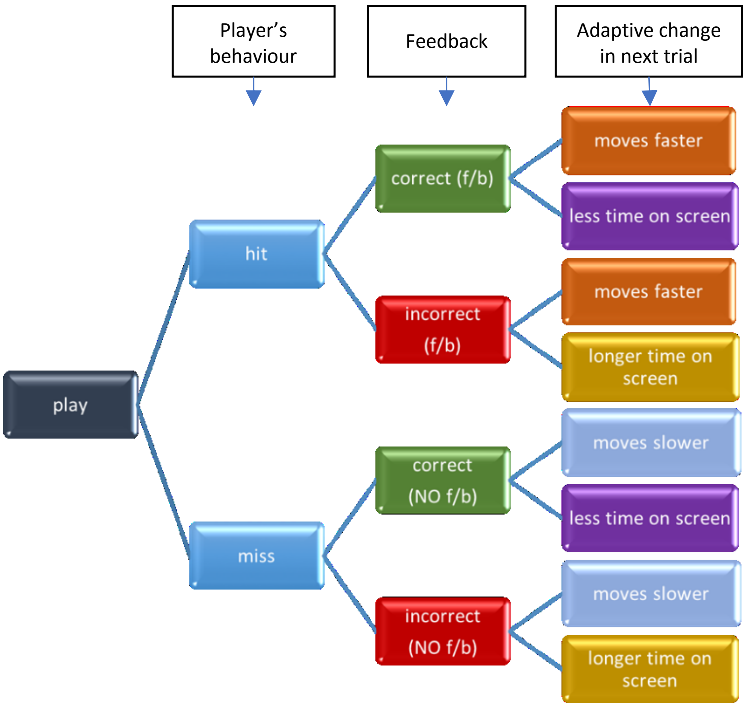


Figure 4.8. Adaptive feature sequence used in Game-like task 1. This includes the behaviour of the player (hit or miss the number), the type of feedback (correct/incorrect per action) and the subsequent change in the behaviour of the object on screen according to the two previous factors. Depending on the combination of player response and feedback, objects can change their speed of movement and the time they appear on screen, which maintains the challenge provided to the player in terms of the speed of the object and its duration on the screen. For the static condition, this adaptive feature was applied only in terms of time on screen.

Table 4.1

Classification of hits during game play in Game-like task 1

Player's behaviour	Interpretation	Type of response	Initials
Player clicks on the box with the correct answer.	Player has identified the prime number.	Correct hit	CH
Player fails to click on box with correct answer but hits a nearby area.	Player has identified the number but misses the position of it.	Correct miss	CM
Player clicks on box with incorrect answer.	Player misidentified the prime number.	Incorrect hit	IH
Player clicks nearby box with incorrect answer but not on it.	Player misidentified the number and misses its position.	Incorrect miss	IM
Player makes no attempt to respond.	Player is either waiting for the prime to appear or does not know the answer.	No response	NR

Finally, Game-like task 1 did not include sounds of any kind. Sounds or music are a typical feature of computer games for marking events such as winning or losing, the start and the end of a game, accelerating the pace or marking the near end of lives, fuel, coins, etc. They certainly add to the engagement, challenge and immersion while playing (Plass et al., 2015). However, in this case, including sounds or music would have added an extra variable to consider. In order to adhere to the simple purpose of trying to test the motion versus the static feature of the objects on screen, the use of sounds was deemed unnecessary (for the moment).

Game-like task 2

Game-like task 2 preserved the same learning goal as the previous game-like task, but some of its mechanics were changed to give a more realistic game feel. The principle behind the gaming task concept was to make it as a first-person shooter game without the violence component that most of these games in the market contain. This type of games, which are among the most popular and successful action games, offer a mechanism that aims at generating a constant challenge to where attention is placed with the need of switching from focused to broader attention (Colzato et al., 2010, 2013).

Following the insights from the multiple object tracking paradigm, Game-like task 2 included four items (boxes) on screen (1 target and 3 distractors) as this is the number suggested by studies using MOT/MIT tasks to be the ideal for an accurate tracking that maintains divided attention (Pylyshyn & Storm, 1988). Only one of the boxes contained a prime number, preserving the same proportion used in the previous gaming task as well as to make the feedback more seamless into the flow of the task. In order to promote a continuous flow of the game-like task, it was coded to contain both conditions in an alternate fashion to one sole task. It also changed the mechanics of feedback provision associating it with visuals and sounds. The modifications to the gaming task stem from the observation of the usability of Game-like task 1 in Experiments 1 and 2 and to create a gamified task with more game-like features to engage players.

After brainstorming and sketching, the initial idea led to the final design which included changes in the colour palette and shapes as well as the game mechanics. A palette of colours that resemble the game Mario Bros. was preferred in order to give this gamified laboratory task a closer approximation to a real and well-known computer game. Also, the new game-like task altered the mechanics in terms of how players could catch the correct number. In the previous gaming task, players used the mouse to play as they clicked on either the actual box with the number wherever this was located on the screen (for motion condition) or the button SELECT (for the static condition). In Game-like task 2, the controls were transferred to the keyboard (*Figure 4.9*) which emulated the use of gamepads, but with a different handling of the buttons.

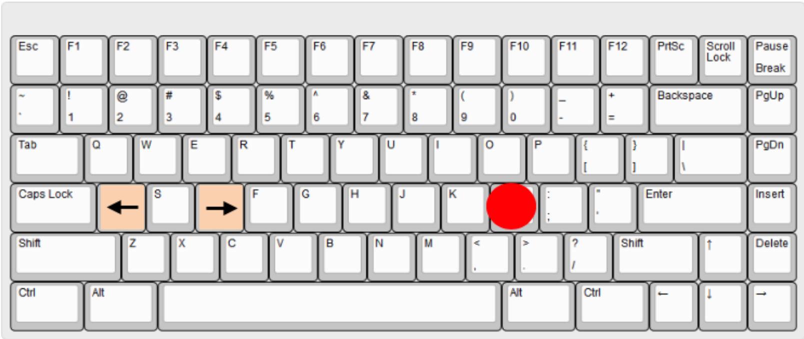


Figure 4.9. Keyboard labelled to play Game-like task 2. In the motion condition, the arrows allowed the player to move the aim to the left or the right along the central line and the red button served as a fire button, i.e. choose the response. In the static condition, the arrow moved clockwise or anticlockwise to highlight the chosen box.

Figure 4.10 depicts screenshots of Game-like task 2 used in the Experimental Phase 2. The task began in the static condition in which players used the keyboard to jump from number to number. This is indicated on screen by the change of colour of the boxes that contain the numbers as they are selected. To mark their choice, i.e. shoot at the number, they pressed the red key indicated on the keyboard. Once the response was made, feedback was provided and then the motion trial began. In this one, the screen was divided by a central line, and four boxes containing different numbers appeared moving in a random trajectory. An aim (vertical line) in the middle was used to reach the boxes when they passed through the middle line. This could be moved from side to side along the central line using the arrows labelled on the keyboard. Once the aim was on the desired target, players could 'fire at' (mark) their response. Feedback followed each marked response.

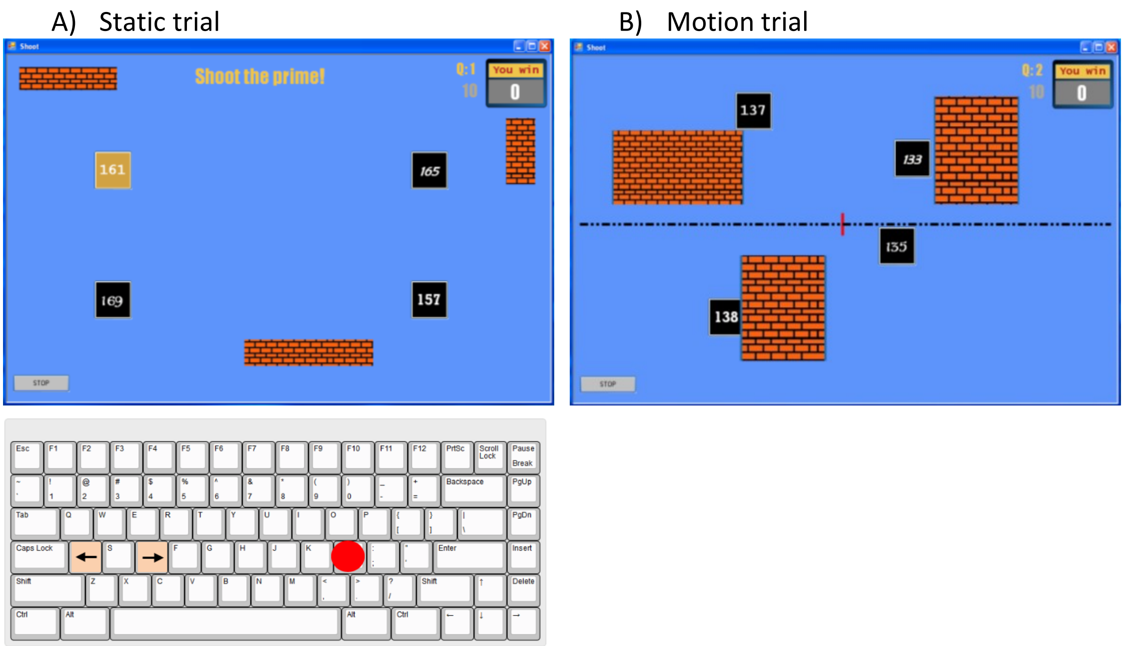


Figure 4.10. Game-like task 2 type of trial. Panel A) The left screenshot shows the static trial in which four numbers are displayed and players need to press the arrow keys to select (change in colour) the desired box and shoot at it by pressing the red button key. Panel B) depicts the layout of the motion trials in which numbers move around the screen and disappear behind the static walls on the course of their trajectory. Players need to use the arrows to move the red aim to the left or right of the screen. When numbers cross the central line and the red aim is in the middle forming a cross, players can shoot. The screenshot on the right shows a correct answer with an explosion and the box displayed in green.

To provide feedback, each marked response was followed by distinctive sounds and colours associated with the type of response (*Figure 4.11*). Correct responses had a visual and auditory on-screen explosion and the marked box changed its colour to green. Incorrect responses were followed by a declining beeping sound (like the one used for representing mistakes in regular computer systems) and the marked box turned red. Both types of trials had the same way of providing feedback. This type of feedback provision was adopted to avoid interruptions to the flow and considered more aligned with the stylistic features of video games. Similar to Game-like task 1, players added 10 points to their score for correct responses and none for incorrect ones. No discounts were applied to the score due to incorrect responses either.

A) Positive feedback B) Negative feedback

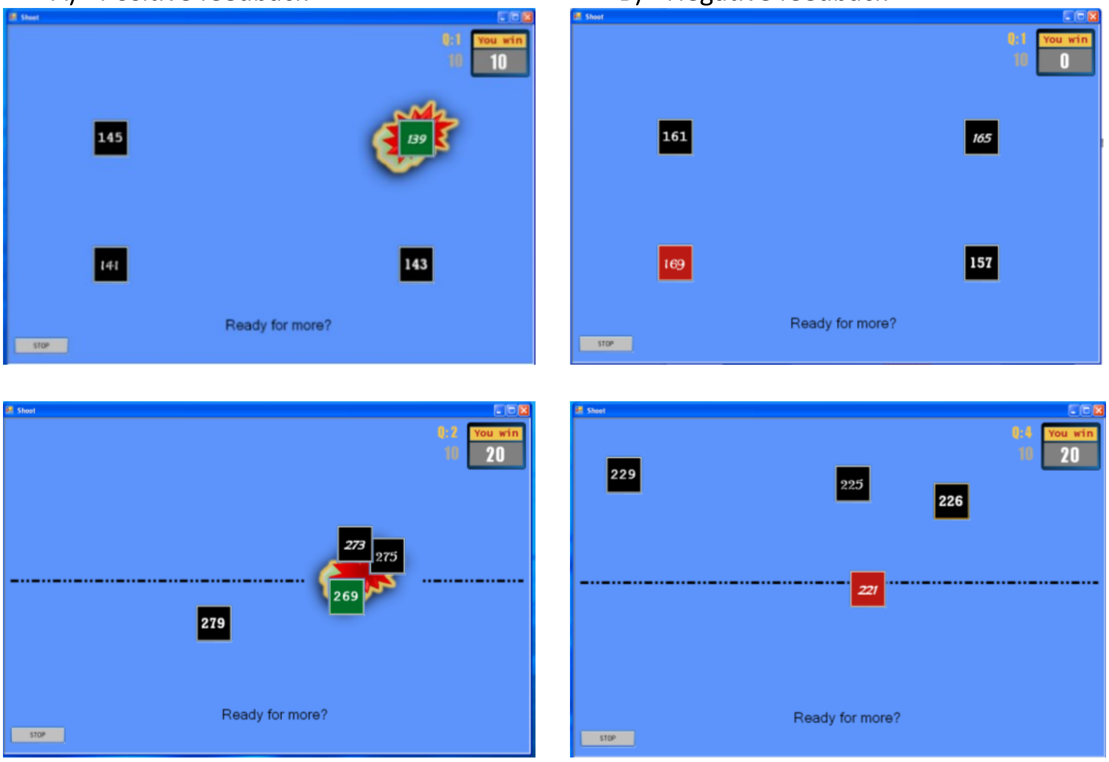


Figure 4.11. Game-like task 2 feedback screens. Panel A) shows feedback for a correct response using visuals and sound for the static (upper) and the motion (lower) trials. Panel B) shows feedback for incorrect responses in which the explosion is omitted. The upper panel shows the static trial while the lower, the motion trial.

The gaming task continued in an alternating fashion until all trials were completed. Each trial had a maximum duration of 25 seconds (i.e. with no responses provided). A consuming time bar indicated the remaining time for each trial. The score was shown in the upper right side of the screen together with the time bar.

Embedding the two conditions in one game-like task facilitated its flow but it created a difference in the time of exposure to the conditions on screen. This was originated in the natural difference in playing the conditions. In the motion trials, players have to wait for the object to pass through the central line to be marked as response whereas in the static trials, players do not have to wait for the object to reach a certain place, enabling a faster response in these trials. In order to balance the amount of time on screen for each condition, an adjustment to the time of presentation of the feedback was introduced based on the time of response of the previous trial, i.e. if the player’s response took less time in a trial than the previous one, then that difference was added to the feedback screen. This adjustment worked well for screen time balance between conditions (*Figure 4.12*) but was perceived as a glitch in the gaming task by the players as they thought the game had 'got stuck' or 'frozen' whenever this occurred.

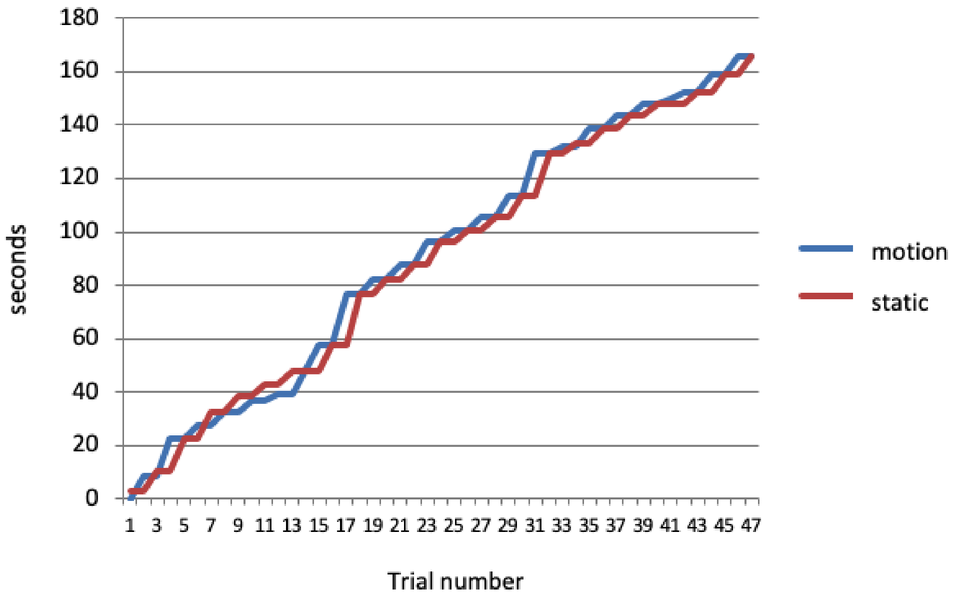


Figure 4.12. Delayed feedback feature. The graph shows how the delayed feedback feature in the code keeps equal times on screen for both alternating conditions. It works by adjusting the times feedback screen based on the immediate prior trial's RT.

The walls were inserted in the motion trials to generate the effect of occlusion of objects in action video games. In the static trials, they were kept with no other function than that of maintaining the same aspect.

It could be argued that Game-like task 2 lacked the technological sophistication that computer games have today in terms of graphics or mechanics. However, it is worth considering that this was a purpose-built gaming task for the investigation of the potential influence of a particular feature of computer games in an experimental setting. Therefore, there was a need to avoid all confoundable variables brought into by a diversity of features that are typical in regular video games. This is an example of the sort of issues reflecting the gap between neuroscience and education that was mentioned above. It is also related to epistemological questions around whether it is possible for a research design to address educational learning using experimental instruments that provide an accurate measure while preserving a degree of ecological validity and authenticity of the task that best represent an educational process.

On another note, the simplicity in the design does not mean that the game-like task did not fulfil its engagement mission. A classic example of engaging simplicity is the famous game Tetris, created by Alexey Pajitnov and released in 1987. The original game design was absolutely simple and yet highly engaging. So much so, that future attempts to make it more sophisticated in terms of graphics (even in 3D) or using different shapes failed to make it more engaging and even more commercial (Rouse, 2005). The possibility of being both the designer and the programmer of these game-like tasks had strengths and disadvantages. On the one hand, as the iterative and experimental process of design needs a constant loop of feedback between designer and programmer (Rouse, 2005), being in these two roles avoided potential communication problems that normally arise when two people work on a game design. It also equipped me with a better understanding of what was possible to develop by combining design principles and evidence from research on cognition. However, neither of the roles was my initial expertise and this research assumes that as a potential for flaws in the design of the task but also as a potential for developing a more logical and abstract way of thinking and further understanding of how technologies might be involved in educational learning.

4.3.3.6 Assessment task

An assessment task to test the recall of learning was designed following a computer-based format to maintain coherence with the gaming task play interface. The test – identical for pre and posttests, except for the randomisation of trials – recorded accuracy and response time automatically. This was a time-constrained multiple-choice task (four options/question) and did not provide any feedback. Participants were asked to select the prime number from a list of four options (Figure 4.13) by pressing the corresponding key on the keyboard (set up with the same symbols on screen).

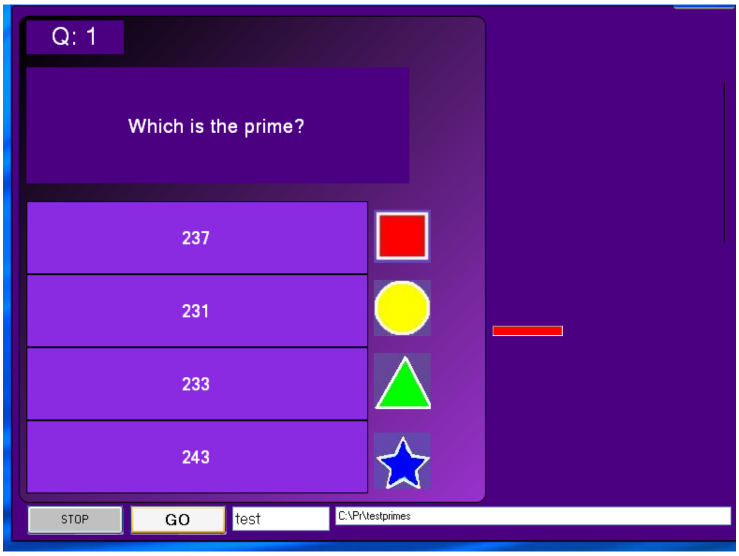


Figure 4.13. Computer-based pre and posttests tasks. Four options were presented in each question. The symbol next to each number is also indicated in a labelled computer keyboard. A consuming-time bar represents the time left for answering.

In terms of appearance, colours were preserved to maintain the visual environment that had been experienced while playing the gaming task. The aim of preserving the visual features was to facilitate the recall and transfer of knowledge by maintaining a degree of similarity with the learning task´s visual environment. However, evidence of skills transfer after video game play is mixed and not conclusive (Barnett, 2014). Perhaps, the difference between the learning and the assessment environments presents an extra degree of difficulty to show transference of skills or knowledge acquired through game play to other less similar environments. This is the challenge of educational video games as they need to be close enough in context to produce transfer, but distant enough as well in order to be perceived as a game and not as a learning task (Green, 2014).

4.3.3.7 Corpora

The game-like tasks were intended to produce the learning of novel content. With the aim of preserving as much ecological validity as possible, it was decided to work with prime numbers as it seemed a natural concept to be learned because it is a mathematical fact. Most people would know the first prime numbers or those below 50, but nothing over three digits (Zazkis, 2005). After that, they need mental calculation or memory. Several methods have been described by which individuals determine whether a number is prime or not: factorisation (break numbers into factors), divisibility rules and factorisation trees (Dixon, 1984; Zazkis & Campbell, 1996; Zazkis & Liljedahl, 2004). Before playing the gaming tasks, players were only given the rule for prime numbers[1]. However, its use or any other tactics were hardly possible while playing because the corpora included big numbers under a time constraint dynamic. Participants were expected to initially attempt to use some of the strategies previously described or even do trial and error with the game-like task feedback given after correct/incorrect responses but once they had identified a prime number, it was expected that players would largely rely on its recall as an example of a maths fact. Correct identification would require attentional processes in place to be prepared for (alerting) and to detect (orienting) the position of the number and distractors, including any change of the number or its location. The involvement of working memory would allow players to keep the number maintained in their attention while they performed the task of tracking the number.

Four learning corpora were devised with numbers over 100 (Table 4.2 and Table 4.3). Each corpus comprised five prime numbers, each prime is embedded in a series of 3 distractors. All distractors were in a close range to the prime number and they were the same for each corpus. In all cases, prime numbers in the corpora summed to the same amount in both pairs (C1 and C2; C3 and C4) in order to balance number magnitude, and the distractors were selected to be as similar as possible in all trials to the target (the prime) in order to balance distance. Corpus 1 and 2 were used with Game-like task 1 while corpus 3 and 4 were used with Game-like task 2. Distractors and their solutions were the same for both corpora in Experiment 1, but a small modification to the distractors was introduced from Experiment 2 onwards. As a repetitive exposure of the distractors was noticed, they were changed to make them all different and avoid their learning through repetitive exposition. The series of numbers were randomly mixed with each new trial.

[1] A number is a prime when it has only two factors, 1 and itself. Therefore, '5' is a prime number because it can be divided by 1 and 5 only. However, '9' is not a prime number because it has three factors, i.e. it can be divided by 1, 9 but also 3.

Table 4.2
Corpora of Numbers Used with Game-like Task 1

Corpus 1				Corpus 2			
Prime numbers	Distractors			Prime numbers	Distractors		
137	133	135	138	139	133	135	138
151	153	155	159	157	153	155	159
229	221	225	226	233	235	237	247
269	261	265	267	263	261	265	267
337	335	339	341	331	335	339	341

Note. Prime numbers add to a total sum of 1123

Table 4.3
Corpora of Numbers Used with Game-like Task 2

Corpus 3				Corpus 4			
Prime numbers	Distractors			Prime numbers	Distractors		
131	117	129	121	127	119	133	141
149	143	147	153	163	161	169	159
181	203	217	221	179	171	183	189
193	243	247	267	191	219	231	237
379	369	391	387	373	319	343	341

Note. Prime numbers add to a total sum of 1033

4.3.4 Procedures

All tasks were performed in a dedicated computer laboratory at the university and involved individual sessions. Following the corresponding ethical formalities and explanation for each of the steps of the session, participants completed the computer-based tasks, including pre and posttests and the game-like tasks on a 18.8 x 10.6 inches *iiyama* monitor using a labelled keyboard (as previously indicated) and a mouse if necessary.

Experiments 1 to 4 were performed individually, and Experiment 5 was conducted in pairs as per the nature of the game. Participants were briefed on the session stages and the approximate time for each task. For all tasks, participants were informed of the aims and rules of the game, and questions about the instructions were promptly responded to (Appendix IV). A trial test of the gaming task (Except in Experiments 1 and 2) was allowed in order to test their understanding and command of the keyboard before the official trial began. A different corpus was used for the practice trials. Participants could start playing when they felt ready for it. A scoreboard with a list of scores under pseudonyms from previous participants was kept visible in the room where participants played the task. This was to show the performance of previous players and encourage competition in players. The use of scoreboard systems in video games started with arcade games which allowed players who reach the highest scores to enter their initials at the end of the game (Reisner, 2016). Their use fosters players to emulate patterns within the game that would make them reach the highest scores which involve actions oriented to engage with the game actively, using memory and applying strategies to win (Gazzard, 2011; Reisner, 2016). The physical scoreboard used in the room aimed at recreating such an environment within video games in order to engage players into making everything possible to beat the scores.

After finishing all tasks, participants were debriefed on the purposes of the study and asked some general and informal questions about their experience with the gaming task. Their scores obtained during game play were added to a ranking chart on a whiteboard.

4.3.5 Data management and analysis

Data from the game play and the pre and posttests were automatically stored in the computer where the test was taken. These data were then transferred to a spreadsheet and loaded to the university server. No data was stored in a personal computer or memory units.

All data was coded under the date of birth of participants. The only register with complete data from participants was the informed consent form (on paper) which was stored in a locked cabinet in the same laboratory during the time of the study and later shredded. There is no manner to trace back individual data with participants identification.

A board with scores was kept on sight in the laboratory room to foster participant's engagement in the task. This contained only the participant's chosen pseudonym and score and there was no form to match them with the real person as they were not placed in order on the board.

Data were analysed statistically using the adequate statistical test and using IBM Statistical Package SPSS 25. The analysis presented in each section was separated according to the hypotheses of the study and that are related to the assessment task (H_1 and H_2). Additional analyses incorporated the performance of the learning corpora and the correlation between response time and trial number during game play. Although they were not intended to test the hypotheses, they informed how the gaming task was operating (Table 4.4). The testing stage contains the mean scores obtained from each individual difference score between post and pretest expressed as a percentage of the correct responses from the total presented. This was then tested for difference using a paired samples *t*-test for each level of the dependent variable. The game play data analysis corresponds to the mean number of types of correct responses per trial number. All tests are reported as 2-tailed. It needs to be noted that due to the game mechanics which involves a time for tracking the target number, it is not possible to count on an exact RT figure for game play and the difference between conditions cannot reveal faster or slower recognition due to this same reason.

Table 4.4
Organisation and presentation of data analysis

Experimental stage	Levels	Data is ordered by	Sources of data	Statistical test	Visual representation
Testing (Assessment Task)	Accuracy (H_1)	Number of participants	Mean scores per participant per condition	Normality test Paired-samples *t*-test	Descriptives table Box plot
	Response time (H_2)		Mean RT per participant per condition	Normality test Paired-samples *t*-test	Descriptives table Box plot
Corpora analysis	Frequency of prime numbers identified	Prime numbers per corpus	Percentage of hits during game play	N/A	Descriptives table

4.3.6 Organisation of this research

This research is divided into two experimental phases which correspond to the video game-like tasks used for understanding the effect of attentive tracking of objects in motion as part of the game play in declarative memory formation (Table 4.5). Phase 1 was dedicated to investigating at a basic level whether tracking objects in motion in a video game-like task had an impact on declarative memory through the design and coding of a game-like task that would emulate random trajectories of an object containing a changing number. In addition to answering the research questions, this phase was also intended to validate the basic experimental design with an aim to develop an ecologically-valid methodology. Phase 2 involved the use of a redesigned game task with more game-like elements and with an increased level of difficulty in order to improve the engagement with the task. This phase explored the effects of visual tracking on declarative memory when more elements were on screen and with the competitive element of playing against another player. The following table summarises the stages of this research.

Table 4.5
Summary of Phases and Experiments

	Experimental Phase 1		**Experimental Phase 2**		
	Experiment 1	***Experiment 2***	***Experiment 3***	***Experiment 4***	***Experiment 5***
Aim	Effect of tracking moving objects on declarative memory	Effect of tracking moving objects on declarative memory with extended game play time	Effect of tracking multiple moving objects on declarative memory	Effect of tracking multiple objects and static occluders – 1P	Effect of tracking multiple objects and static occluders – 2P
Task	Game-like task 1	Game-like task 1	Game-like task 2	Game-like task 2	Game-like task 2
DV	Accuracy & RT	Accuracy & RT	Accuracy & RT	Accuracy & RT	Accuracy & RT
IV	Motion and Static	2 (Motion & Static) x 6 (Time)	Motion and Static	Motion and Static	Motion and Static
Participants	20	16	19	50	52
Corpora	C1 & C2	C1 & C2 (unique distractors)	C3 & C4 (unique distractors)	C3 & C4 (unique distractors)	C3 & C4 (unique distractors)
Game-like task elements	• 1 element on screen • Visual concrete feedback • No sound • Play with mouse • Each condition with its task • 1-player game mode	• 1 element on screen • Visual concrete feedback • No sound • Play with mouse • Each condition with its task • 1-player game mode	• 4 elements on screen • Audio-visual conceptual feedback • Written feedback • Distinct object colour • Play with keyboard • Both conditions in 1 task • 1-player game mode	• 4 elements on screen • Audio-visual conceptual feedback • Unique colour • Play with keyboard • Both conditions in 1 task • Occluders on screen • 1-player game mode	• 4 elements on screen • Audio-visual conceptual feedback • Unique colour • Play with keyboard • Both conditions in 1 task • Occluders on screen • 2-player game mode
Trials	15 each condition	20 each condition	45 (22 motion, 23 static)	100 (50 each cond.)	100 (50 each cond.)
Play time	6.25 minutes per condition	8.33 minutes per condition for 5 days	18.75 minutes combined	20.83 minutes combined	20.83 minutes combined

4.3.7 Ethics

This research complied with all ethical approval steps and requirements according to the University of Bristol Ethics committee (Appendix V). None of the studies involved physical harm or risk to participants and all sensitive matters related to anonymisation of information as well as secure storage of data were correctly addressed.

Issues regarding recruitment of participants increased with new GDPR norms that came in force amidst data collection, particularly during Experimental Phase 2. As a researcher, I was permanently aware of the importance of maintaining a position in line with new regulations which imposed a tension between what needed to be done (recruiting participants) and what should be respected (new regulations in place). This issue was handled in the best possible way, not without difficulties, respecting the new regulations concerning privacy rights and adopting alternative mechanism that involved a more direct and personalised way of informing potential participants about the research in order to recruit participation without coercing their participation while trying not to trespass the new established privacy boundaries.

This research is also concerned with aspects of integrity of the research project as well as the researcher who conducts it. As Macfarlane (2009) points out, the concept of integrity in research should stem from the combination of the researcher's values with their practice of research. The several stages of this research project have presented different situations and demands in which the decisions made have demonstrated traits of the values entailed in this project, such as honesty, respect, discipline, humility and perseverance. These have been reflected and practised through the discipline and perseverence required for designing a game-like task while learning how to do it; the balance between honesty and respect necessary for recruiting participants through motivating their engagement into participation; the honesty, discipline and humility for analysing vast amounts of data correctly and acknowledging the lack of evidence despite the effort invested in the task; and the humility and perseverance to acknowledge success cautiously and momentarily.

4.4 Summary of the chapter

This chapter has addressed the approach and methods used in this research, with a special emphasis on the philosophical issues that an educational neuroscience approach entails for the research of human learning from both a science and a social perspective; in this case, the understanding of human learning by associating knowledge from the natural sciences (cognitive neuroscience) and the social sciences (education). The lack of a unified philosophical stance to approach the phenomenon of human learning from an educational neuroscience perspective means there is still a gap to consolidate the field. This should be no reason for not undertaking this view when researching human learning in the context of education. However, even if a design can be assumed to be philosophically aligned to both areas, caution must be taken especially regarding the gap between distant traditions of research and methodologies.

The need for laboratory experiments has been justified as the first step of research in the field of educational neuroscience in order to consolidate knowledge that could then be applied in more contextual interventions. Nevertheless, these laboratory experiments might need to prioritise educational aims by testing in more ecologically-valid tasks or environments that could be later translated into real classroom contexts. With this need in mind, two game-like tasks were designed and built for conducting the experiments in this research. This chapter described these tasks as well as the general procedures and measures used in this research. More details of each experiment will be provided in the following chapters.

Chapter 5 Experimental Phase 1 – Exploring motion and learning in a video game-like task

This empirical chapter shows the two first studies of Experimental Phase 1 conducted to explore the extent to which the effects of tracking and acting upon objects in motion could enhance declarative memory. Experiment 1 aimed at testing the declarative learning through the feature of motion embedded in a single object containing semantic information in a video game-like interface and comparing its effect on learning with a static-element version of the same gaming task. Experiment 2 stemmed from the analysis of the first experiment and tested the hypotheses using the same gaming task with minor modifications in an extended game play format. These initial exploratory experiments served also to test the behaviour of both the gaming and assessment tasks.

5.1 Overview of Experimental Phase 1

Chapter 3 provided a theoretical rationale for investigating the effects of visual motion tracking on declarative memory. The visual tracking of objects in motion is associated with a deployment of attentional resources to support the binding of location and information of the object via the interaction of processes involving attention and working memory. Based on that rationale, this research investigated how educational video games may produce learning and hypothesised that moving learning stimuli can be recalled faster and more accurately than static learning stimuli presented in a learning video game-like task. The design of the experimental tasks incorporated not only traditional elements of video game design in order to promote the players' engagement needed as a precursor for learning, but also the understandings of the elements that promote effective visual motion tracking of objects conducive to a higher performance (i.e. less interference with cognitive load) in recall during game play.

This first experimental phase involved two studies – Experiment 1 and Experiment 2 using the game task denominated Game-like task 1. The aim was to explore the research question and also test the ecological validity of the experimental paradigm. Both experiments used a game-like task that included the tracking of a single object containing the learning stimulus that was expected to be recalled in the posttest. Experiment 2 contained adjustments that naturally stemmed from the insights of the first experiment and explored the influence of extended time of exposure to game play on learning.

5.2 Experiment 1: Exploring the effect of motion v/s static in declarative learning

This first experiment was conducted to explore whether a difference could be established in the learning of novel factual content (prime numbers) between a computer game-like task featuring visual tracking and one with its absence. To that aim, a simple educational video game was built over a coded template. The design was simple and a useful starting point to analyse features and extend the design and mechanics of the gaming task (see section Game-like task 1 on page 65).

Following the general RQ for this research project,

RQ_{main} What is the influence of the movement of learning stimuli, tracked as part of an educational video game-like task, on the declarative memory of their properties, as measured by accuracy and speed of recall?

The following hypotheses were tested:

H_1: Accuracy of responses will be significantly higher for numbers learned under the motion condition compared with those under the static condition measured by the difference between pre and posttest.

H_2: Response time will be significantly lower for numbers learned under the motion condition compared with those under the static condition measured by the difference between pre and posttest.

Hypotheses H_1 and H_2 corresponded to the measure of learning and were answered through the analysis of the assessment task in the testing stage.

5.2.1 Participants

Twenty participants were recruited on a voluntary basis through open invitation via flyers and email within the university.

All were university postgraduate students, 16 females, 4 males (M = 29.04 years of age; SD = 5.0). Participants were from different cultural backgrounds and academic subjects, which offered a varied sample with multiple and diverse interests. Their involvement with video games was also diverse and more inclined to the non-player end of the continuum. They all had normal to corrected vision and were in a healthy condition at the time of the experiment.

5.2.2 Design

The study followed a pre-posttest within-participants experimental design. Two dependent variables – accuracy and RT – were defined by the difference between pretest and posttest. The two conditions of game play were the levels of the independent variable, which are related to the presence or absence of the motion feature in the computer game-like task, namely 'motion**'** and 'static**'**.

The sample size allowed a distribution in four counterbalanced groups (Table 5.1).

Table 5.1
Group Distribution Design – Experiment 1

Group	Pretest	Condition 1	Corpus	Condition 2	Corpus	Posttest
1	X	Static	C1	Motion	C2	X
2	X	Motion	C1	Static	C2	X
3	X	Static	C2	Motion	C1	X
4	X	Motion	C2	Static	C1	X

5.2.3 Tasks and materials

Game-like task 1 was presented in two separate versions each corresponding to the conditions, motion and static. Each gaming task version consisted of 15 trials of 25 seconds maximum duration. This gives the task a total maximum duration of 6.25 minutes. Each trial presented randomly four different numbers for the duration of the trial or until a choice was marked by clicking the mouse in the corresponding area according to the condition being played (Figure 4.4). For this experiment, Game-like task 1 offered a maximum total score of 150 points which was visible for participants during the gaming task and refreshed every time they marked a correct response.

The assessment task used in this experiment consisted of ten questions each presented for a maximum of 25 seconds in which the participant could respond. Each question appeared only once and contained the numbers of both corpora 1 and 2. Participants used a labelled keyboard to answer (Figure 4.13). No feedback was provided to the participants on this task until the end of the experiment.

Both the gaming and the assessment tasks were completed using corpora 1 and 2.

5.2.4 Procedure

All tasks were performed in a dedicated computer laboratory and involved individual sessions (See specific details in Procedures 4.3.4). For all tasks, participants were explained the aims and rules of the game and questions about the instructions were promptly responded to (Appendix IV). There was no time allocated for practice and participants started playing immediately after instructions were given and they feel prepared to commence.

5.2.5 Results

The analyses here presented involve all players' response times (for correct responses only) and performance accuracy for both stages: testing and game play. For each stage, analyses were performed separately for accuracy and response time.

A first section present results for responding hypotheses H_1 and H_2 using the data from the assessment task. Analyses of pre and posttests were used to check the learning transfer of knowledge under the two conditions compared.

A second section presents a set of additional analyses with data from game play accuracy per trial and the percentage of recognition of the prime number corpora. These analyses served the purpose of illustrating how learning developed during game play and were also helpful in rectifying and improving elements of the gaming task for the subsequent experiments, such as helping identify a suitable time of exposure to game play.

5.2.5.1 Hypotheses H_1 and H_2

Results from the difference between pre and posttests were analysed in order to establish a possible difference between the two conditions for accuracy and RT. The means for accuracy and RT were estimated per participant for pre and posttests. RT was calculated only over correct answers. However, in the total absence of correct answers, it was not possible to assign the value zero (0) because lower values imply faster recognition, and this would skew the distribution. Discarding the sample was not considered either, due to the small sample size and also because having no accuracy had a meaning in itself. Therefore, in cases with no correct results, the total amount of time for a trial without response, i.e. 25 seconds, was the value assigned as RT in such cases.

Accuracy and RT were analysed separately. Descriptive statistics are shown first and plots showing a test of difference between the two conditions. Paired-samples *t*-test was used as statistical inferential test.

Accuracy – H_1

Table 5.2 summarises the means representing accuracy for each condition and their corresponding tests. The descriptive statistics show that the static condition recorded a higher difference between pre and posttest compared to the motion condition. The pretest was equal for both conditions, but players could actually recognise more numbers learned in the static condition in the posttest. Posttests mean scores for correct responses showed a minor increase in the recognition of prime numbers in both conditions but slightly higher for the static condition.

Table 5.2
Descriptive Statistics for Accuracy (%) and Response Time (seconds) – Experiment 1

	Motion			Static		
	Pretest	Posttest	Difference	Pretest	Posttest	Difference
Accuracy (percent)						
N	20	20	20	20	20	20
Mean	35.00	40.00	5.00	35.00	48.00	13
Std. Deviation	24.17	26.75	32.36	19.33	27.83	26.97
Minimum	0	0	-60	0	0	-40
Maximum	80	100	80	60	100	60
Response time (seconds)						
N	20	20	20	20	20	20
Mean	13.00	8.55	-4.44	13.03	9.85	-3.18
Std. Deviation	6.11	7.28	10.85	6.37	6.86	7.42
Minimum	4.83	2.70	-18.87	4.52	3.68	-18.64
Maximum	25.00	25.00	19.37	25.00	25.00	14.11

The mean difference between pre and posttest for each condition was calculated. A Kolmogorov-Smirnov test determined the distribution of scores was normal for the accuracy $D(20) = .164$, $p = .192$. Therefore, a parametric test of difference was used to establish the difference between the conditions for the variable of accuracy.

Figure 5.1 shows the difference between pre and posttest for both conditions. The mean scores for the motion condition seem more spread out than the compacted shape for the static condition. The median difference between pre and posttest was higher for the static condition, despite maximum values being obtained in the motion condition. A mean difference of 8% between conditions essentially shows no statistical significant difference between conditions as shown by a paired-samples *t*-test, $t(19) = -1.04$, $p = .314$, $d = 0.27$, establishing that the motion feature within the video game-like task made no difference in the learning of prime numbers – measured by accuracy levels – compared to when the numbers remained stationary on the screen.

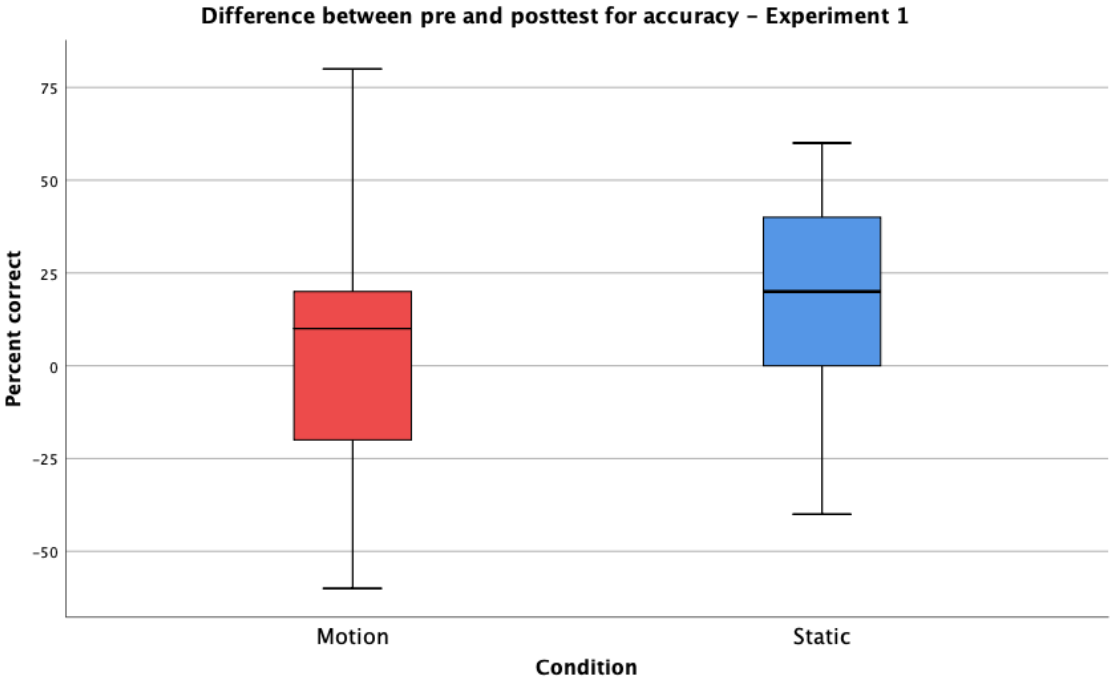


Figure 5.1. Difference between pre and posttest for accuracy in Experiment 1. A mean difference percentage of the correct responses has been calculated by subtracting the the mean pretest and posttest scores per participant. This difference is presented here per condition.

Response time – H_2

In the assessment task, very brief response times indicate immediate recognition. The testing is a computerised multiple-choice task with no elements of gaming. Table 5.2 shows prime numbers in the motion condition were recognised faster than those learned in the static, by -1.26 seconds of difference.

The assumption of normality of the distribution was violated for the variable of response time, $D(20) = .255$, $p = .001$. It was, however, decided to use a parametric test due to the robustness of the test in relation to Type I error (Rasch & Guiard, 2004; Wiedermann & von Eye, 2013) and also because response time distributions tend to violate normality and are often positively skewed (Baayen & Milin, 2010).

Figure 5.2 shows the distribution of the mean difference in RT between conditions. The speed of recognition of prime numbers measured by the mean difference between pre and posttest was lower for those numbers learned under the motion condition (*M* = -4.44 seconds, *SD* = 10.85) compared to the static condition (*M* = -3.18 seconds, *SD* = 7.42), with a mean difference of 1.26 seconds. However, this difference between conditions was not statistically significant, $t(19) = -.439$, $p = .665$, $d = 0.14$. Therefore, the feature of motion made no difference in the speed of recognition of the prime numbers compared to the static version of the game-like task.

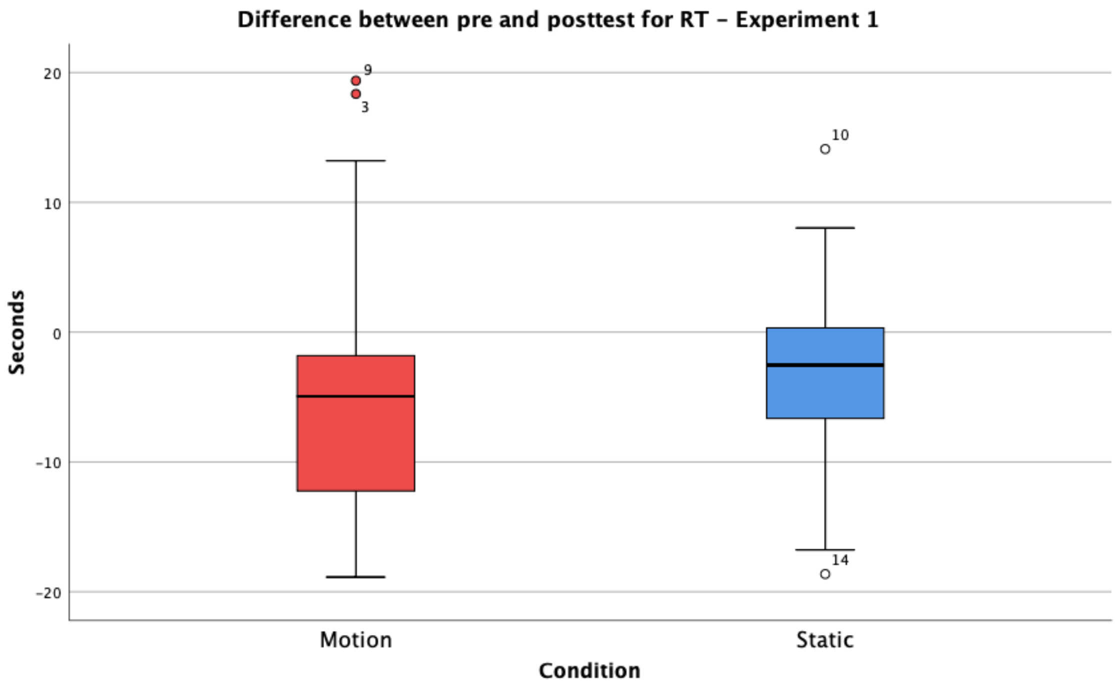


Figure 5.2. Difference between pre and posttest for response time in Experiment 1. Response times are expressed in seconds and each condition shows the mean difference in response time between the pre and the posttest tasks per condition. Outliers are also represented for each condition.

5.2.5.2 Additional analyses – Game play and Corpora accuracy

Game-like task 1 in Experiment 1 - Accuracy

The mean time played was 2.74 (*SD* = 0.84) minutes in the motion condition and 2.25 (*SD* = 0.76) minutes in the static condition to complete the 15 trials per condition.

Game play analysis involves calculating the mean number of correct responses per trial per participant. This measurement was plotted against trial number to show the trend in learning in each of the conditions during game play. This was not done for data from response time during game play as they do not represent exact response time due to the game mechanics in which players have to track the object and wait for it to be marked as a response. For this reason, the descriptive data are only used to inform the behaviour of faster recognition during game play within each condition, without establishing comparisons between them.

Table 5.3 contains descriptive statistics for each of the types of hits in each condition (Refer to Table 4.1 for a description of the codes) that had a total of 15 trials. Some of the trials contained no information either because there was no marked response by the player.

Table 5.3
Descriptive Statistics for Game Play Performance (Accuracy and Response Time)

			N	M	SD
Motion	Accuracy	CH	15	10.80	2.24
		CM	15	4.13	1.81
		IH	15	7.87	2.26
		IM	15	5.07	4.53
		NR	15	74.07	12.89
	Response time	CH	15	1.20	0.10
		CM	13	0.80	0.36
		IH	15	1.28	0.15
		IM	12	ND	ND
		NR	15	1.77	0.18
Static	Accuracy	CH	15	10.00	2.07
		CM	15	0.00	0.00
		IH	15	8.53	1.85
		IM	15	0.00	0.00
		NR	15	47.67	9.93
	Response time	CH	15	0.99	0.11
		CM	12	ND	ND
		IH	15	1.01	0.13
		IM	8	ND	ND
		NR	15	1.99	0.06

ND: No data. Values for accuracy correspond to the sum of items while values for RT correspond to their mean

The mean number of hits was calculated per trial according to their type (see description in Table 4.1) in order to form an idea of how game play occurs. Figure 5.3 shows the highest proportion of answers recorded for each condition is actually a *no response* (NR) in both conditions. This trend seems slightly higher in the motion version of the game, which does not necessarily mean that the answer is not known but that perhaps the player makes an effort in ascertaining the correct response once the number is identified as a prime, instead of purely playing and guessing.

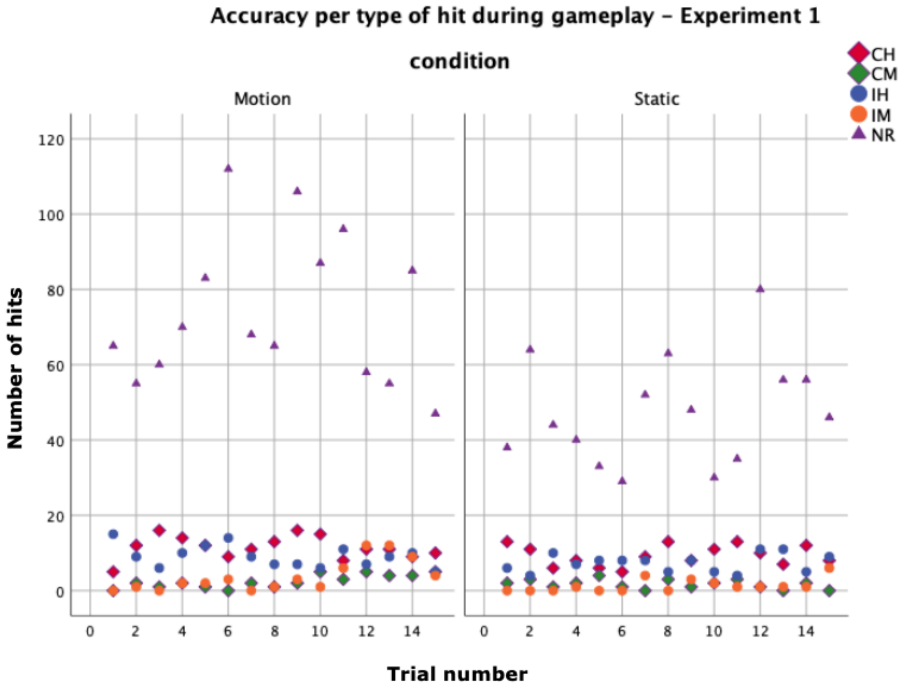


Figure 5.3. Accuracy per type of hits during game play in Experiment 1. Types of hits in Game-like task 1 (CH: correct hit; CM: correct miss; IH: incorrect hit; IM: incorrect miss; NR: no response). The motion condition shows a higher number of NR and an increment of CM towards the end that could probably be attributed to the built-in difficulty level as the game progresses.

Figure 5.4 shows the trend in recognition of prime numbers during game play and includes both correct hits and correct misses as separate lines. When comparing conditions visually, they seem to have a similar behaviour in terms of correct responses during game play, showing almost no difference between themselves. Regarding the correct misses, the motion condition seems to have recorded more of these occasions perhaps due to the active nature of the game and the need to track a number that represents a higher level of difficulty when marking the number. In comparison, the static condition would not be expected to invoke many ‘correct-miss’ type of hits due to the static nature of the objects on screen. The occurrence of a correct miss in this case could be more related to a problem with being distracted while playing (time on task) or not being able to master the game mechanics.

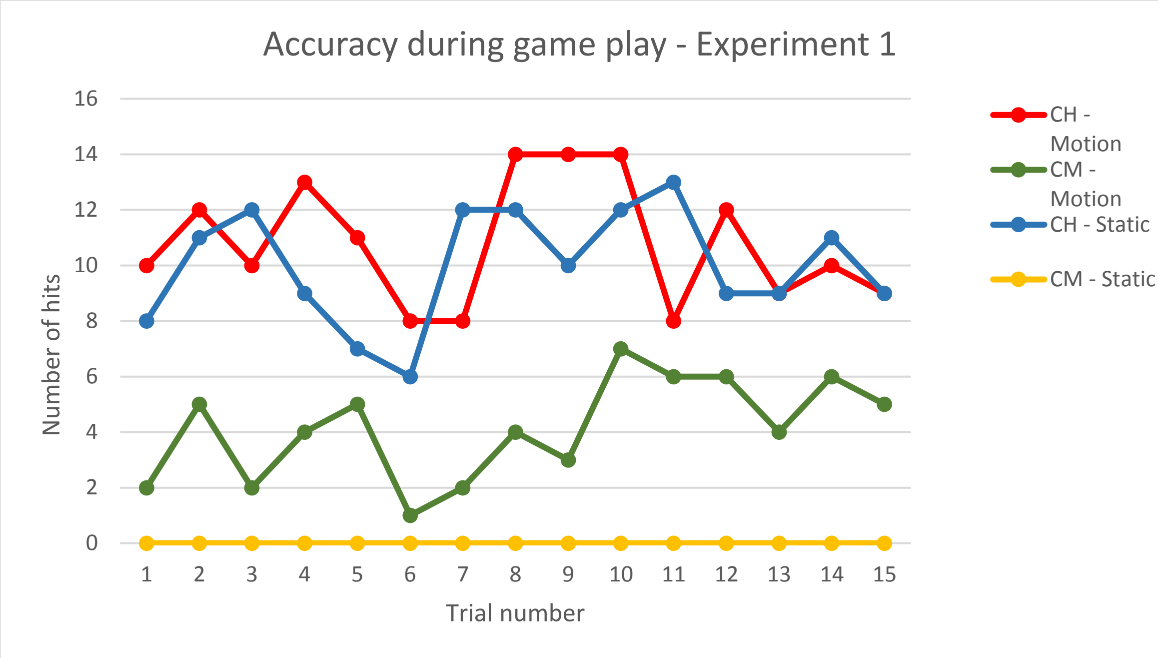


Figure 5.4. Accuracy during game play in Experiment 1. Separate lines are shown for the mean number of correct hit (CH) and correct miss (CM) per trial for each condition, motion and static.

A measure combining two types of responses such as 'correct hit' and 'correct miss' was deemed a better indicator of game play performance. Figure 5.5 shows players' performance during game play when both types of answers are combined (CH and CM) with the motion condition having more hits despite the challenges in the game. As a combined measure, accuracy is on average higher for the motion condition (Motion = 14.93, *SD* = 3.31; Static = 10.00 hits, *SD* = 2.07), showing that prime numbers were recognised more in this condition. However, this could have also possibly been an effect of the game mechanics leading players to make more attempts to click on the number as this one moved on the screen.

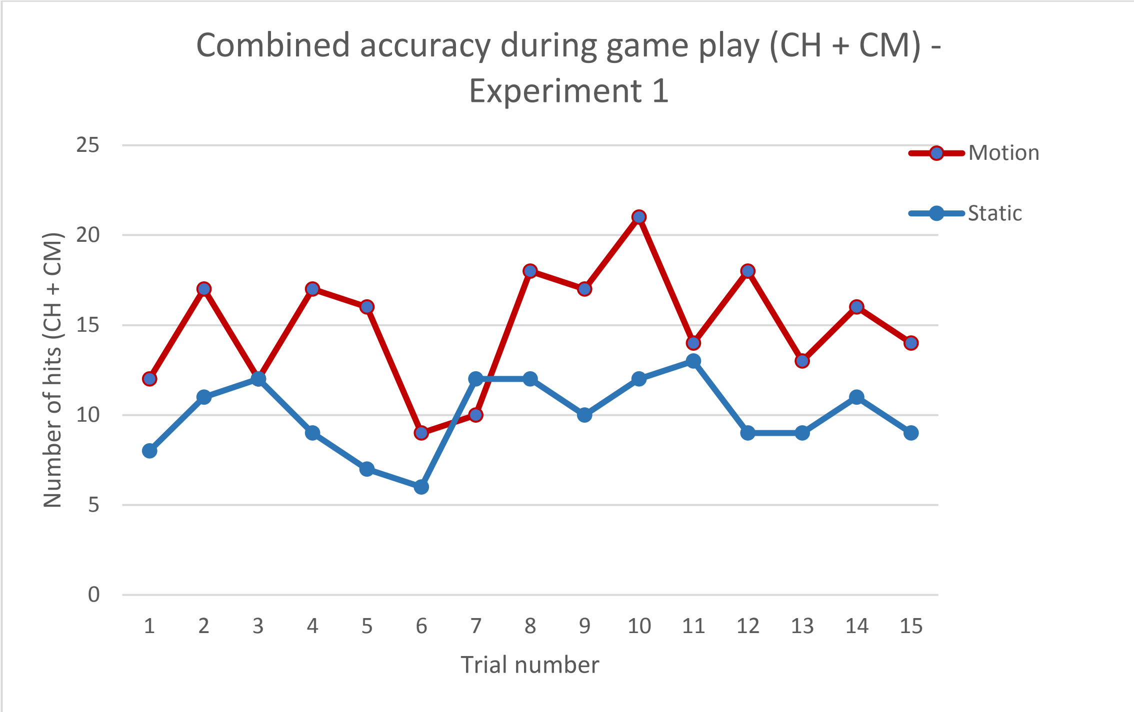


Figure 5.5. Combined measure of accuracy during game play (CH + CM) in Experiment 1. Separate lines show a combined measure using correct hit (CH) and correct miss (CM) types of answer to illustrate game play performance per condition.

Figure 5.5 illustrates how the combined measure can offer different information regarding the recognition of prime numbers while playing. The higher mean score under the motion condition provides an indication of the game's capacity to promote recall even with a more challenging feature that might have well behaved as a deterrent for engagement and, consequently affected the possibility for learning. Therefore, despite the increased difficulty associated with tracking incrementally faster targets, recognition of these targets was maintained over the trials.

Corpora analysis

With the aim of understanding more how the learning stimuli worked during game play, Table 5.4 shows the performance percentage of prime numbers based on the number of times the prime numbers appeared (which is random) and the number of correct responses (CHs only). The numbers are presented without distinguishing the condition under which they were hit with the purpose to know the general rate of recognition of the numbers presented in the game. Primes appeared on average 255.4 times (SD = 40.3). Some of them appeared as highly recognisable during game play and behaved more or less similarly while there was only one number that showed a very low percentage of recognition during game play (prime number *269* with only a 4%). The average performance was 13.23% (*SD* = 4.85) with half the numbers above the average.

Table 5.4
Corpora Performance During Game play – Experiment 1

	137	151	229	269	337	139	157	233	263	331
No. of times appeared	235	221	304	324	203	263	237	249	296	222
Number of CH	32	39	28	13	38	30	39	32	28	42
Performance (%)	13.62	17.65	9.21	4.01	18.72	11.41	16.46	12.85	9.46	18.92

5.2.6 Discussion of Experiment 1

Experiment 1 investigated the theoretical assumptions of a relationship between tracking objects in motion containing semantic information and learning implemented in a video game for learning. This first experiment tested whether the tracking of objects in motion in the form of video game play had an effect on the learning of prime numbers. Participants played Game-like task 1 in two versions (motion and static) separately and were tested before and after playing for their declarative memory on the topic of prime numbers.

The analyses from the comparison of pre and posttest showed no statistical significant differences in accuracy performance (H_1) and faster recognition (H_2) between the conditions. Therefore, Experiment 1 showed no evidence to support the idea that objects in motion can enhance the declarative learning of information contained in such objects when compared to a stationary object.

Research on video games that claims a myriad of positive effects on different cognitive skills is abundant, e.g. enhanced attentional skills, spatial cognition, visual working memory (Bediou et al., 2018; Blacker et al., 2014; Blacker & Curby, 2013). However, they also use a variety of designs and materials that makes it difficult for establishing comparisons. A meta-analysis by Powers and colleagues (2013) has shown that, while different types of video games and experimental designs might have similar effects on information processing, true experiments involving players with different skills have shown almost no effects in executive tasks and have from small to medium size effects in other domains such as visual processing. Nevertheless, Prena et al. (2018) suggested that video game mechanics as well as time spent in playing had an effect on declarative memory formation. They found that in games that featured a reward mechanism, participants did better in a post declarative memory task than when it was absent in a game. The lack of results in learning through objects in motion from Experiment 1 led to the question of whether the context for declarative memory formation was appropriate and whether it enabled a sensitive way of measurement. Therefore, a focus on analysing the role of the different features involved in the game mechanics was needed to enhance the design for a further experiments.

It was evidenced that the time played in Experiment 1 was less than three minutes on average per condition, which may have been insufficient for learning the information presented (measured as accurate and faster recall). Due to the simple design of Game-like task 1, there were no further stages to enable extended game play time without sacrificing the players' engagement and time on task. Hence, the possibility for learning may have been too brief and insufficient for players to demonstrate levels of accuracy in the assessment task. Time-on-task or deliberate practice (Ericsson et al., 1993) has been deemed the best predictor for the acquisition of skills, such as mastering a video game for better performance (Röhlcke et al., 2018). This engagement on the task is somehow affected by factors, such as motivation, and time on task (too much or not enough) can in turn act as a detrimental mechanism for attentional performance, needed to succeed in a cognitive task (Sarter et al., 2006).

The design of the assessment task provided only one opportunity for the demonstration of recall, i.e. each prime number was asked only once. This may have restricted the possibility of obtaining sufficient information into how much players recalled what they had just learned. Anecdotal data indicated that players were somehow confused by the numbers they were confronted with in the assessment task and that it was hard to distinguish between distractors and targets due to their similarity. This was also problematic in terms of the distractors used as they were the same for each corpus, exceeding the number of times the primes appeared, which may have led to their involuntary learning. The interference of incorrect answers (or lures) is increased in multiple-choice tasks leading sometimes to incorrect knowledge (Roediger & Marsh, 2005). However, the recommendation for the next experiment is to maintain the assessment task and modify the distractors. A multiple choice type of pretest provides information on the player's previous knowledge but at the same time it provides an opportunity for players to improve their ability to learn, as content will be presented ahead of the competitive gaming (Little & Bjork, 2016).

Analysis of the game play showed that players tend to have better accuracy in the motion game despite the potentially greater level of difficulty in responding to a moving target. Game-like task 1 engaged players into the challenge of tracking the numbers, catching them and trying to remember them to earn points. In anecdotal conversation after the session, most participants declared a preference for the motion version of the game despite finding it more difficult to play. At a technical level, the game correctly recorded the information needed. The analysis of scores for individual items in the corpora used suggested that it presented an appropriate challenge with more than half of the numbers being correctly marked above the average during game play. However, this was not translated to the assessment task which showed accuracy going in the opposite direction of the hypothesis, resulting in an increase in prime numbers learned under the static condition in the posttest compared to prettest (although not statistically significant). The interpretation of these trends need to be taken with caution due to the small sample size of this experiment and lack of statistical significance.

Therefore, some modifications to the mechanics of the gaming task were deemed important for the next experiment. As time on task has been indicated as one potential element that can enhance attentional performance and thus cognitive processing, the number of trials was extended. In terms of study design, the next experiment was set to explore how the hypotheses behave in an extended intervention over time. As said above, due to the extended exposure to distractors (because they were the same in both corpora), they were changed to make them all different in the corpora and avoid the learning of incorrect numbers by overexposure. Finally, the assessment task was also modified by increasing the number of questions presented to players and providing further opportunities for recall.

Whereas this brief first experiment has not provided evidence that can support declarative memory formation via visual motion tracking, the game used has shown that learning occurs comparatively when playing a game with objects in motion. These insights have been considered to perform some modifications to continue testing the hypothesis in the next experiment.

5.3 Experiment 2: Exploring the effect of motion v/s static in declarative learning in extensive video game play

Following the conclusions of the previous experiment in which time of exposure to the game was considered a factor for the lack of learning, Experiment 2 aimed to further investigate the influence of motion tracking in the learning of novel content through extensive video game play. This experiment involved the adjustments to Game-like task 1 (set out above), in relation to: increasing the number of trials within the game, the modification to the distractors used (all different), and increasing the number of times a number is tested in the assessment task. The study design was also altered to require participants to play the game in multiple consecutive sessions.

Following the general RQ for this research project,

RQ_{main} What is the influence of the movement of learning stimuli, tracked as part of an educational video game-like task, on the declarative memory of their properties, as measured by accuracy and speed of recall?

And the following hypotheses were explored in this experiment:

H_1: Accuracy of responses will be significantly higher for numbers learned under the motion condition compared with those under the static condition measured by the difference between pre and posttest.

H_2: Response time will be significantly lower for numbers learned under the motion condition compared with those under the static condition measured by the difference between pre and posttest

Hypotheses H_1 and H_2 corresponded to the measure of learning and were answered through the analysis of the assessment task in the testing stage.

5.3.1 Participants

Sixteen postgraduate students, 5 males, 11 females, with little or no video game play experience (M = 33.6 years of age; SD = 7.46) were recruited on a voluntary basis via flyers and emails sent within a university in England. They all had normal to corrected vision and were in a healthy condition at the time of the experiment.

5.3.2 Design

The experiment followed a within-participants pre-posttest design to be conducted in five consecutive days. The dependent variables – accuracy and RT – were measured in relation to two independent variables – condition (two levels: motion and static) and time (six levels: time points). Participants were randomly assigned to one of the distribution groups as they took part in the experiment (Table 5.5) on the first session.

Table 5.5
Distribution grid to counterbalance the conditions in a within-subjects design

Tasks/Groups		1	2	3	4
Day 1	PreT	x	x	x	x
	Cond. 1	S	M	S	M
	C.	1	1	2	2
	Cond. 2	M	S	M	S
	C	2	2	1	1
	PostT	x	x	x	x
Day 2	Cond. 1	M	S	M	S
	C	2	2	1	1
	Cond. 2	S	M	S	M
	C	1	1	2	2
	PostT	x	x	x	x
Day 3	Cond. 1	S	M	S	M
	C	1	1	2	2
	Cond. 2	M	S	M	S
	C	2	2	1	1
	PostT	x	x	x	x
Day 4	Cond. 1	M	S	M	S
	C	2	2	1	1
	Cond. 2	S	M	S	M
	C	1	1	2	2
	PostT	x	x	x	x
Day 5	Cond. 1	S	M	S	M
	C	1	1	2	2
	Cond. 2	M	S	M	S
	C	2	2	1	1
	PostT	x	x	x	x

M = Motion, S = Static, C = Corpus

5.3.3 Tasks and materials

In this experiment, the general design of Game-like task 1 and the assessment task remained essentially unaltered, except for some minor modifications made to the number of trials per game and changes to the distractors used in the corpora. Modifications to the two corpora used in Experiment 1 involved the use of different distractors to avoid their learning by incidental exposure as it is believed might have occurred in Experiment 1; the prime numbers were maintained unaltered (Table 5.6). Each version of the game increased the number of trials to 20, five more than in Experiment 1, which resulted in a maximum total score of 200 points which was visible for participants. Feedback was maintained after each marked response type. Each trial had a total duration of 25 seconds (total time with no responses), which made a total maximum time of 8.33 minutes of game play per condition.

Table 5.6
Comparison of Distractors Used in Corpora 1 and 2

Question	Corpus	Experiment 1				Experiment 2			
		distractors repeated				*Same primes, different distractors*			
1	1	133	137	135	138	133	137	135	138
2	1	151	153	155	159	151	153	155	159
3	1	221	229	225	226	221	229	225	226
4	1	261	265	267	269	273	275	279	269
5	1	335	339	337	341	333	343	337	341
6	2	139	133	135	138	139	141	143	145
7	2	153	157	155	159	157	161	165	169
8	2	247	235	233	237	231	233	237	243
9	2	261	263	265	267	261	263	265	267
10	2	341	339	335	331	329	339	335	331
Sum of prime numbers		1123				1123			

The number of trials in the assessment task was increased from 10 to 40 questions, i.e. every question was asked 4 times, giving players further opportunities to think of the answer during recall. In the previous experiment, anecdotal data suggested confusion of numbers and sometimes pressing the wrong key for responding. The position of the correct answer within the trial was also modified in order to keep track of the marked numbers (Table 5.7). No feedback was provided to participants at this stage until the end of the experiment.

The game and assessment tasks were played on a 18.8" x 10.6" *iiyama* monitor using a mouse and keyboard labelled as in Experiment 1 (Figure 4.13).

Table 5.7

Order of Questions for Testing in Experiment 2

Q.		Set 1				Q.		Set 2				Q.		Set 3				Q.		Set 4			
1	c1	*133*	*137*	*135*	*138*	11	c1	*153*	*138*	*155*	*137*	21	c1	*153*	*138*	*137*	*155*	31	c1	*137*	*138*	*135*	*133*
2	c1	*151*	*153*	*155*	*159*	12	c1	*133*	*151*	*135*	*159*	22	c1	*159*	*135*	*133*	*151*	32	c1	*153*	*155*	*151*	*221*
3	c1	*221*	*229*	*225*	*226*	13	c1	*221*	*225*	*226*	*229*	23	c1	*229*	*225*	*221*	*226*	33	c1	*225*	*226*	*229*	*159*
4	c1	*273*	*275*	*279*	*269*	14	c1	*269*	*273*	*275*	*279*	24	c1	*273*	*269*	*279*	*275*	34	c1	*269*	*273*	*275*	*343*
5	c1	*333*	*343*	*337*	*341*	15	c1	*333*	*337*	*341*	*343*	25	c1	*337*	*343*	*333*	*341*	35	c1	*279*	*333*	*341*	*337*
6	c2	*139*	*141*	*143*	*145*	16	c2	*141*	*145*	*139*	*143*	26	c2	*141*	*139*	*143*	*145*	36	c2	*141*	*145*	*143*	*139*
7	c2	*157*	*161*	*165*	*169*	17	c2	*161*	*169*	*157*	*165*	27	c2	*161*	*157*	*165*	*169*	37	c2	*165*	*161*	*169*	*157*
8	c2	*231*	*233*	*237*	*243*	18	c2	*243*	*231*	*237*	*233*	28	c2	*237*	*231*	*233*	*243*	38	c2	*233*	*231*	*237*	*243*
9	c2	*261*	*263*	*265*	*267*	19	c2	*261*	*265*	*263*	*267*	29	c2	*263*	*265*	*261*	*267*	39	c2	*267*	*265*	*261*	*263*
10	c2	*329*	*339*	*335*	*331*	20	c2	*329*	*331*	*335*	*339*	30	c2	*331*	*335*	*329*	*339*	40	c2	*329*	*335*	*331*	*339*

5.3.4 Procedure

Participants were required to attend five consecutive 1-hour sessions which were held individually in a dedicated computer laboratory. Informed written consent was sought at the beginning of the session 1 followed by a verbal consent sought at the beginning of the following sessions confirming willingness to continue participation.

First, participants were pretested using the assessment task. They then completed the tasks in order according to the group they were randomly assigned to (Table 5.5). Participants played the two conditions of the game twice in an alternate fashion during each session. This gave participants more time of exposure to the game without the need of modifying the stages within Game-like task 1. Once game play was finished, participants completed a posttest which was identical to the pretest. This did not provide feedback and participants were unaware of how they performed until the next session. In the following sessions, participants started directly with the game play session and ended with the posttest. Every session was held individually for approximately an hour which implied a long time for data collection with a small number of participants.

Previous to each session of game play, participants were explained the aims and rules of the game (Appendix IV Game-like task 1) and questions about the instructions were promptly responded. There was no time allocated for practice, and participants started playing immediately after instructions were given and they felt prepared for it.

5.3.5 Results

Analyses presented in this section involve data from the testing stages for hypotheses H_1 and H_2, separately. Descriptive statistics are presented first. Inferential statistics tests corresponded to analysis of variance (ANOVA) using data from the assessment task (pre and posttests). Data from the assessment task was analysed in time points to understand better how the recall from motion compares to the learning via static game play over time.

Due to time constraints, participants could not follow a pattern of attendance, i.e. they did not attend the sessions at the same time of the day. However, no data points were eliminated for this reason. Also, it is important to note that two participants were not able to take part in consecutive days but their data was still considered.

5.3.5.1 *Hypotheses H_1 and H_2*

The multiple within-participant measures over time required a repeated-measures 2 (conditions) x 6 (time points; 1 pretest, 5 posttests) ANOVA to analyse the data collected as mean RT and mean accuracy separately. Table 5.8 shows descriptive statistics for the testing phase in each time point for both accuracy and response time.

Table 5.8
Descriptive Statistics for Accuracy (%) and Response Time (seconds) – Experiment 2

	Motion						Static					
	Pretest	Day 1	Day 2	Day 3	Day 4	Day 5	Pretest	Day 1	Day 2	Day 3	Day 4	Day 5
Accuracy (%)												
N	16	16	16	16	16	16	16	16	16	16	16	16
Mean	41.88	53.74	62.08	75.68	79.81	80.03	39.82	47.07	61.02	66.44	75.99	74.17
SD	19.71	17.83	15.61	21.51	18.52	24.44	15.34	17.70	18.02	16.36	14.44	18.87
Minimum	19.05	22.22	31.58	15.79	31.58	15.79	21.05	20.00	31.82	40.00	42.86	28.57
Maximum	76.19	76.47	90.00	100	100	100	75.00	86.96	95.00	95.00	100	100
Response time (secs)												
N	16	16	16	16	16	16	16	16	16	16	16	16
Mean	9.02	6.79	5.77	4.97	4.52	4.28	8.96	6.43	6.19	5.70	5.48	4.55
SD	3.42	3.20	2.32	1.70	1.53	1.80	3.91	2.75	2.76	2.28	2.22	1.65
Minimum	3.29	3.57	3.24	2.37	2.90	2.25	3.62	3.38	2.35	2.43	2.32	2.61
Maximum	14.61	12.18	12.33	9.06	9.00	9.10	18.69	12.23	12.22	11.68	11.40	8.81

Accuracy – H_1

Table 5.8 depicts the means for correct responses per condition for each session. The pretest showed little difference in the mean scores between the conditions, which increased gradually with game play sessions, but by the end of the fifth session the posttest revealed a small increase in the mean scores between conditions at a descriptive level.

Mauchly's test indicated that sphericity was met for both factors, condition (only two levels, therefore sphericity is met) and for the interaction Condition*Time, $\chi^2(14) = 9.47$, $p = .804$, but not for time, $\chi^2(14) = 25.8$, $p = .030$. Therefore, Greenhouse-Geisser correction was used for establishing a correct *F*-ratio.

There was a significant main effect of time expressed in the number of days of practice over accuracy, $F(2.83, 42.41) = 40.7$, $p < .001$, $\eta^2_{partial} = .73$. However, despite a progressive increase in scores as a product of days of practice, and with a higher mean percentage of accuracy for the motion condition (65.54%) compared to the static condition (60.75%), the difference between the conditions was not statistically significant, $F(1, 15) = 2.34$, $p = .147$, $\eta^2_{partial} = .14$. Additionally, there was no statistically significant interaction between the condition under which numbers were learned and the number of days of practice, $F(5, 75) = .458$, $p = .806$, $\eta^2_{partial} = .030$.

Figure 5.6 shows the trajectory of mean scores from the pre-test over the five days. Day 2 shows almost no difference in the recognition of prime numbers regardless of the condition in which they were learned. However, Day 3 marks a change in direction for both conditions which appears to reach a closer point on Day 4 to separate again on Day 5, showing a mean higher recall of prime numbers learned under the game that involves visual tracking. These differences between conditions per time point are, however, not statistically significant.

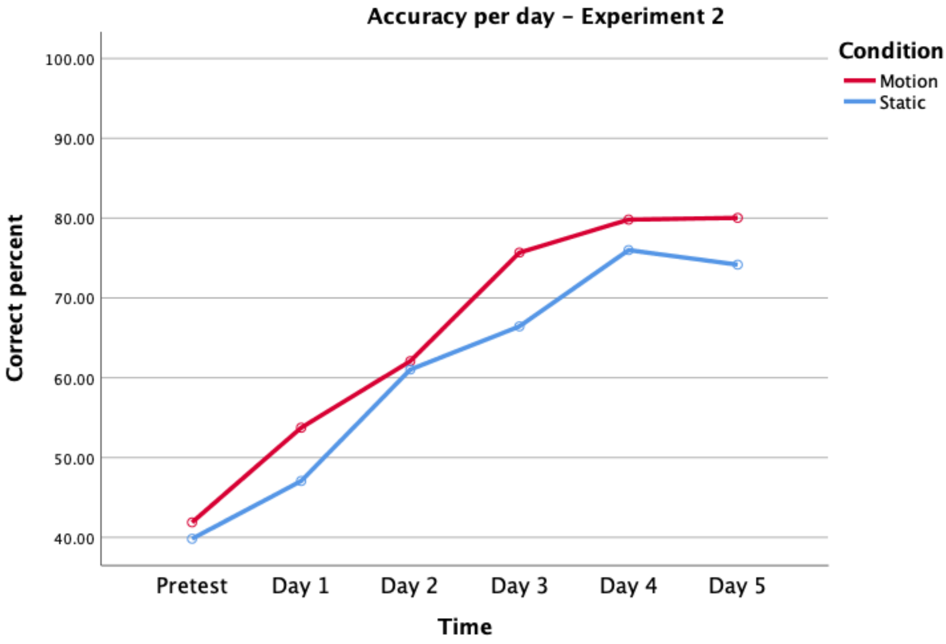


Figure 5.6. Mean accuracy performance (in percentages) per day per condition in Experiment 2. Mean difference in scores from pretest and posttest were converted into percentage of accuracy per participant and a mean percent was calculated per day to show the progression of learning per condition.

Response time – H_2

Only RTs for correct responses were included in the analyses. Table 5.8 shows mean RTs under each condition for each session. RTs were shorter for numbers learned in the motion game compared to the static, even when a tendency towards a decrease appears in both conditions.

Mauchly's test indicated that sphericity assumption was violated for the factor time, $\chi^2(14) = 61$, $p < .001$ and for the interaction condition*time, $\chi^2(14) = 30$, $p = .009$. Therefore, values were adjusted to Greenhouse-Geisser. The sphericity assumption was met for the condition factor as there were only 2 conditions.

There was no significant interaction between conditions and time of exposure to the game, $F(2.6, 39.1) = 2.0$, $p = .139$, $\eta^2_{partial} = .12$. There was, however, a significant main effect of time $F(2.15, 32.3) = 20.1$, $p < .001$, $\eta^2_{partial} = .57$ expressed in the number of days players were exposed to the game. Prime numbers learned under the motion condition were recognised at a faster rate (5.9 mean seconds) compared to the static condition (6.23 mean seconds). This difference, though small, was statistically significant, *F*(1, 15) = 4.58, *p* = .049, $\eta^2_{partial}$ = .23.

Figure 5.7 depicts the mean RTs at different time points showing the decrease in RT from the pre-test to the first post-test and from then onwards, the values continued descending but the motion condition seems to have a stronger impact and numbers learned through tracking seem to be recognised more rapidly in the testing stage. Two time points showed statistically significant difference between conditions. On Day 3, players showed a faster recognition of prime numbers in the posttest for the motion condition (*M* = 4.97 seconds, *SD* = 1.70) compared to the static version (*M* = 5.70, *SD* = 2.28), *t*(15) = -3.10, *p* = .007, *d* = 0.77 95% CI [-1.22, -.23]. Day 4 showed a further reduction in response time in the motion condition (*M* = 4.52, *SD* = 1.53) and in the static condition (*M* = 5.48, *SD* = 2.22). This difference between conditions for Day 4 was also statistically significant, *t*(15) = -4.17, *p* = .001, *d* = 1.04 95% CI [-1.44, -.46]. This increase in speed of recognition for numbers learned in the motion condition was soon reached by those numbers learned in the static version of the game, suggesting there might be a window for the tracking of objects in motion to start having an effect on this aspect of learning.

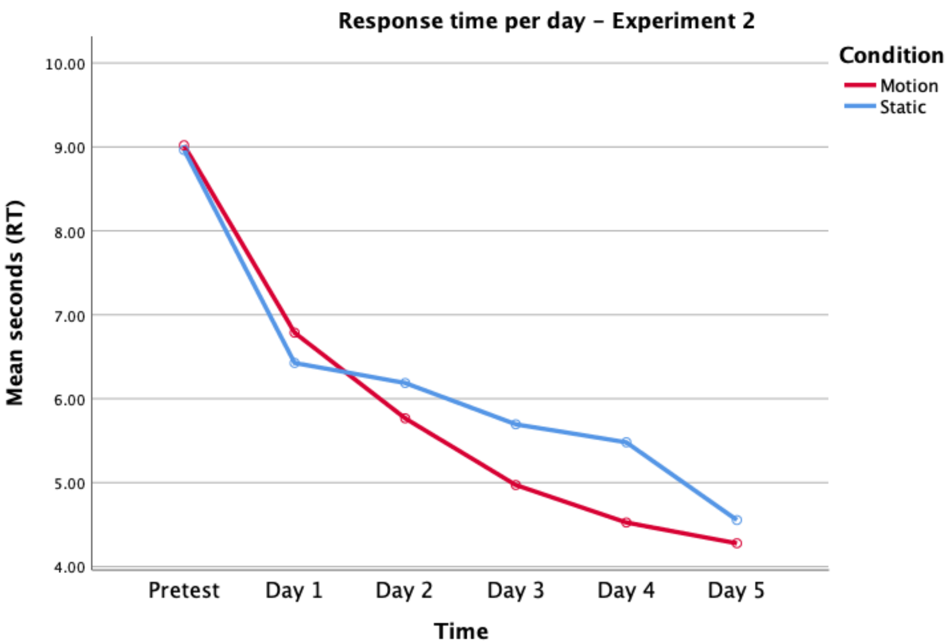


Figure 5.7. Mean response time values per day in Experiment 2. Response time values correspond to the mean difference in seconds between pretest and posttest per day. This illustrate the progression of faster recognition over time for each of the conditions.

5.3.5.2 Additional analyses – Game play accuracy and corpora analysis

Game-like task 1 in Experiment 2 - Accuracy

Participants played on average 6.17 minutes daily with the motion game and 4.59 minutes average for the static version of Game-like task 1. Similar to Experiment 1, data from game play were recorded following the types of answers provided by the players (Table 4.1). The number of each of the type of responses was accounted for as well as their mean RTs. For the analyses, only correct hits (CH) and correct misses (CM) were considered for both accuracy and response time.

Table 5.9 shows descriptive statistics with a general overview of the results obtained. These values were plotted against the trial number and the type of response to portray the learning relationship over time during game play.

Table 5.9
Summary of Descriptive Statistics per Type of Response during Game Play – Experiment 2

	Motion					Static				
	CH	CM	IH	IM	NR	CH	CM	IH	IM	NR
Accuracy (Number)										
N	20	20	20	20	20	20	20	20	20	20
Mean	21.73	15.25	8.02	17.49	169.16	22.23	0	9.79	0	59.33
SD	2.11	13.26	1.44	17.27	137.72	1.40	0	1.31	1	12.45
Response time (secs)										
N	20	20	20	20	20	20	10	20	8	20
Mean	1.06	0.63	1.13	0.53	1.32	0.90	0.66	0.91	0.78	1.60
SD	0.13	0.25	0.15	0.21	0.53	0.12	0.33	0.18	0.52	0.27

CH = correct hit; CM = correct miss; IH = incorrect hit; IM = incorrect miss; NR = no response

Accuracy corresponds to the number of correct hits during game play. Additionally, the correct-miss type of hit was added to the correct hits to analyse a combined accuracy measure for game play.

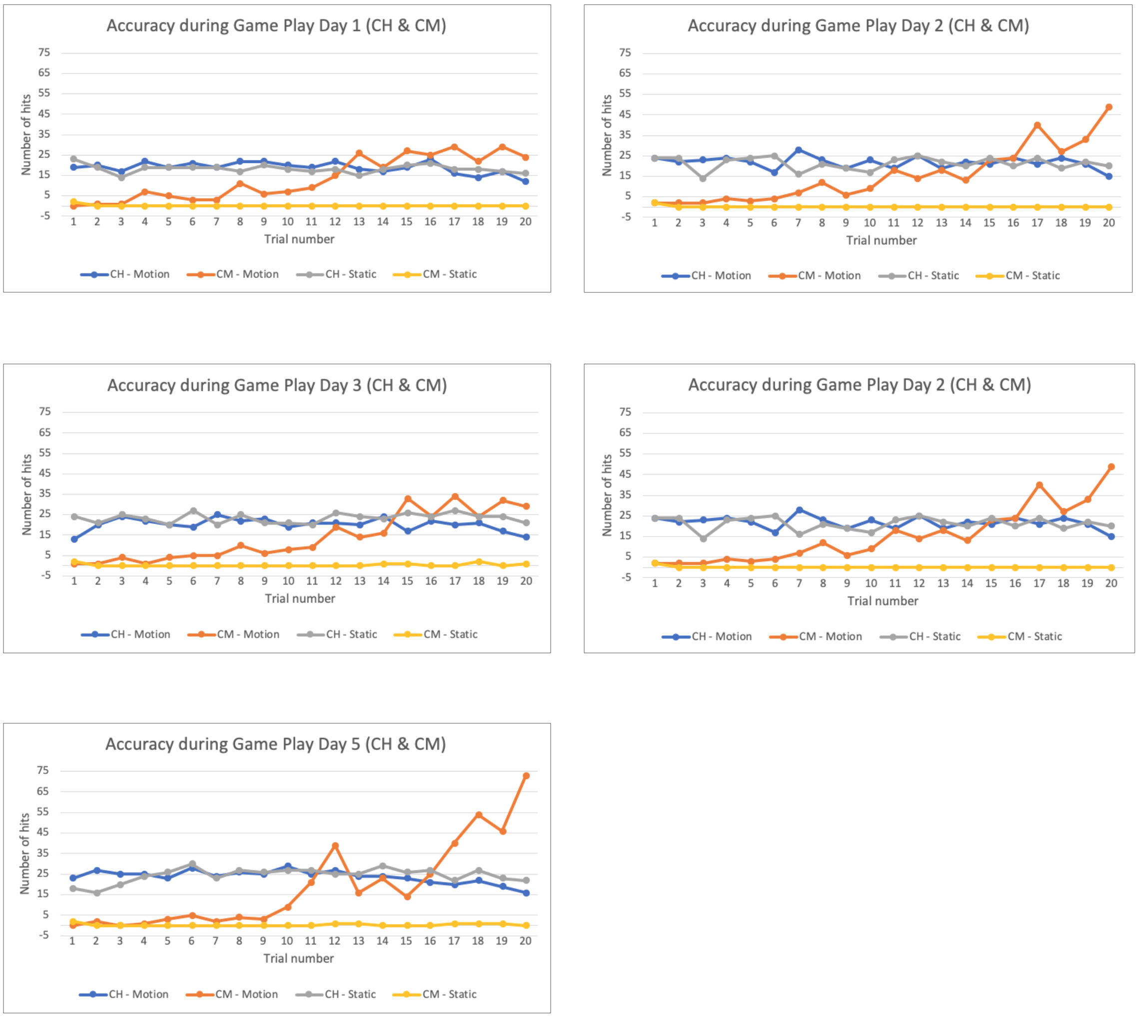


Figure 5.8. Mean combined measure of accuracy during game play. The adaptive feature of the game allows the display of the number of correct missed responses when players are performing in more challenging trials. The correct miss type of response shows an increase for the motion condition towards the final day, indicating a higher recognition of prime numbers even in challenging trials. On Day 5 this indicator of correct misses is higher than in the previous days by 20 points on average.

Figure 5.8 shows the trend for CHs and CMs for both conditions per day. While most days the number of correct hits for both conditions showed similar performance, CM for the motion condition grew as the game progressed and players gained more practice with the game. CM indicates correct recognition of the prime number but failure to mark it, possibly due to the increasing speed of change and motion of the targets.

Figure 5.9 depicts a mean accuracy performance estimate for the five days of game play that only includes the number of CHs. Performance under the motion condition decreases as the game progresses and increases in difficulty in terms of time of exposure and speed of motion. This adaptive feature was intended for providing a level of challenge to players based on their individual differences as game players and maintaining, therefore, their engagement on the task. Therefore, the reason for a combined measure, i.e. CH + CM, to account for accuracy performance lies in the nature of such adaptive feature of the game design. This feature revealed the real identification of the targets regardless of the difficulty of the trial as it might occur in a real game, i.e. the challenges posed by the game mechanics may have made it difficult to mark the response, but that cannot be understood as a lack of identification of the target, which is in itself a correct missed response. Hence, a combined accuracy (CM + CH) was deemed more precise as a measure of the identification of the targets. Figure 5.10 and Figure 5.11 show the combined measure for both conditions first separated by day and then all combined as a result of 5 days of game play.

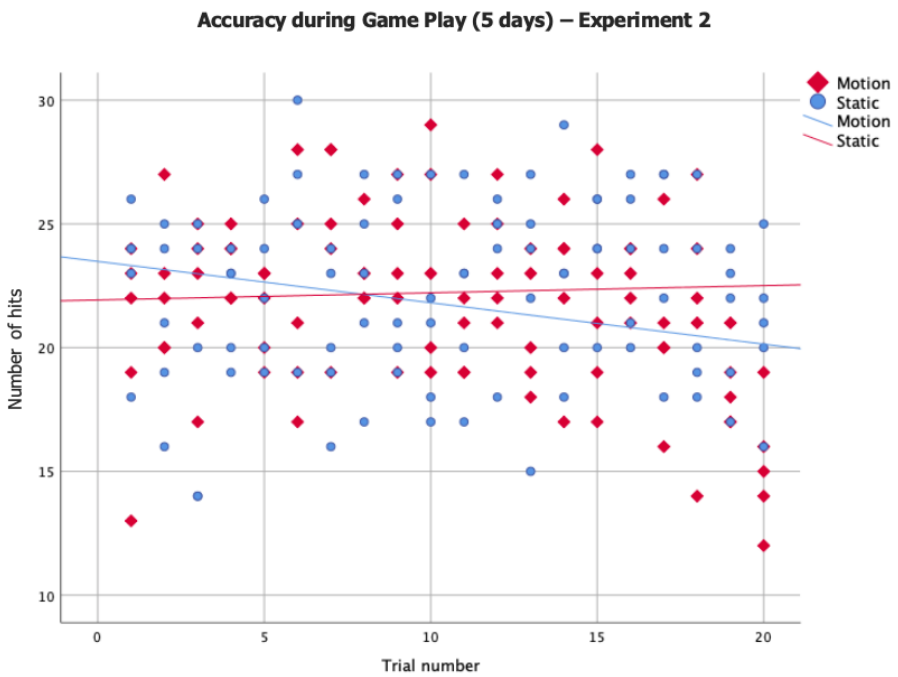


Figure 5.9 Mean accuracy during game play (5 days) in Experiment 2. A mean value of the single measure that includes only correct hits is shown per trial number per condition.

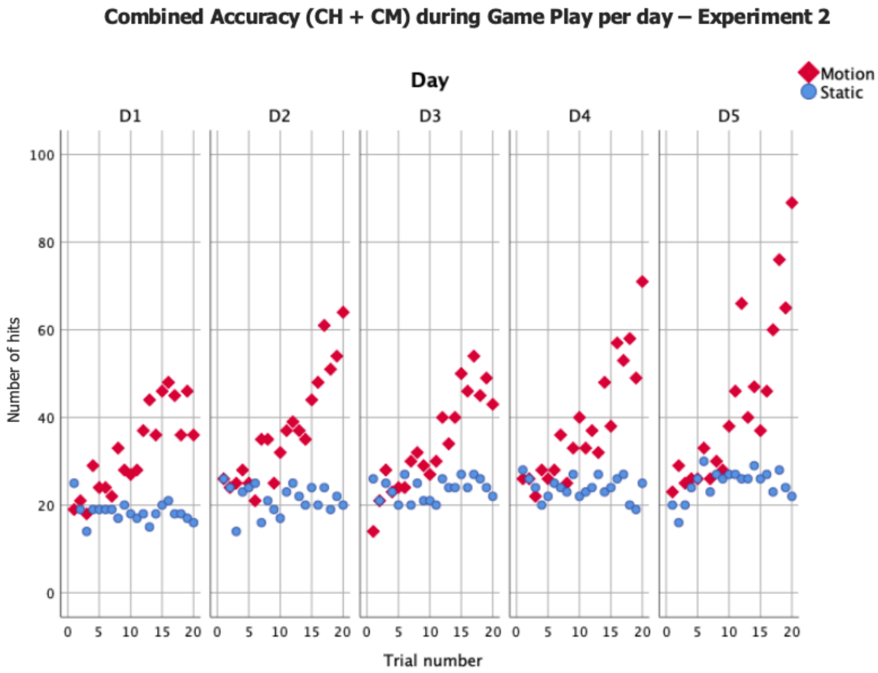


Figure 5.10. Combined measure of accuracy during game play per day in Experiment 2. This measure adds the correct hits and the correct miss type of response to illustrate the recognition of prime numbers increases with the number of trials and with the number of days. This increase in hits seems more favourable in the motion condition of the game-like task.

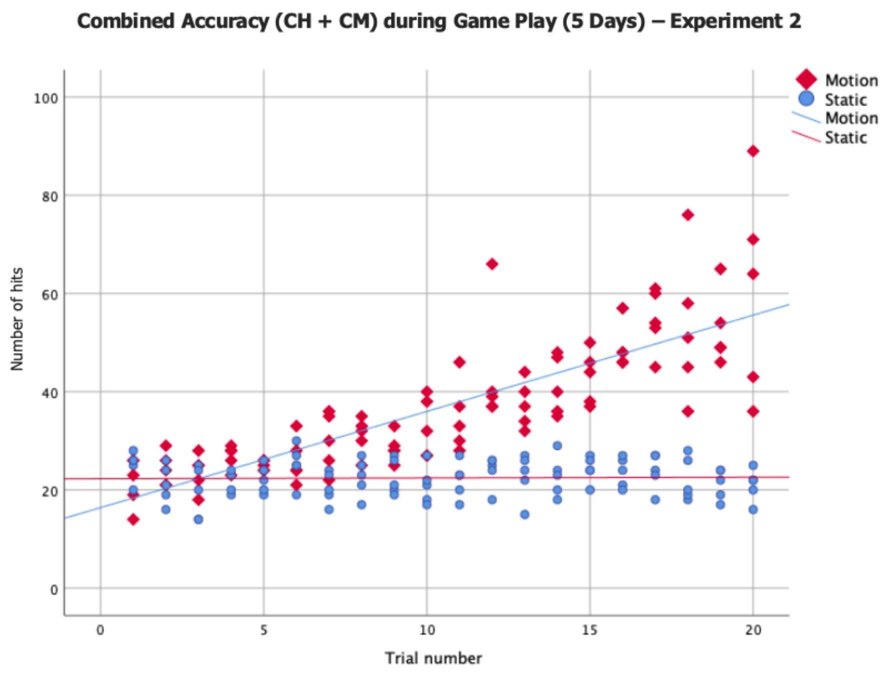


Figure 5.11. Combined measure of accuracy during game play (5 days) in Experiment 2. A mean number of combined hits over 5 days is represented here per trial. Progressively higher increments appear in the motion version of the game-like task.

Corpora analysis

Accuracy data during game play was also relevant to analyse the corpora used for this experiment. Table 5.10 shows the detail for accuracy performance of the prime numbers used. While some of them are highly recognised, especially if they are smaller numbers, others are recognised on average only half of the time they appear. Primes appeared on average 670 times (*SD* = 153.2). More exposure to the task through extended play increased their recognition during game play compared to the rate of recognition in Experiment 1 in which the time of exposure was considerably shorter. The average performance was 68.15% (*SD* = 17.85) which was higher than the mean performance in Experiment 1 (13.23%), but in this case only four prime numbers are above the average.

Table 5.10
Corpora Performance During Game play – Experiment 2

	137	151	229	269	337	139	157	233	263	331
Number of times appeared	523	560	678	737	917	484	532	638	729	902
Number of CH	498	512	452	395	477	395	441	324	396	478
Performance (%)	95.2	91.43	66.67	53.6	52.02	81.61	82.89	50.78	54.32	52.99

5.3.6 Discussion of Experiment 2

Experiment 2 examined the effects of motion tracking on declarative learning through extensive game play. Participants played Game-like task 1 for five days and were tested after each session. There was no statistically significant interaction between condition and time on the better recall of prime numbers, but practice in the form of extended game play across five days had a statistically significant effect on speed of recognition of prime numbers learned under the motion condition, which provides evidence to support H_2 on the effect of motion tracking on the speed of recognition of prime numbers. This finding differed from Experiment 1 and highlights the importance of time-on-task for learning.

As with Experiment 1, findings for the present experiment cannot support H_1 as there was no significant difference between the conditions for accuracy of responses. However, unlike the previous experiment, the means in accuracy for the motion condition were in the direction of the hypothesis.

These findings of lack of accuracy but faster recognition of prime numbers learned under the motion game might be explained by the different cognitive demands each condition presented to the players. Nelson and Strachan (2009) found a difference in the way the type of video game affected the cognitive strategies developed after games are played. In their experiment, players became faster respondents in consecutive tasks after playing action video games but less accurate compared to players of puzzle games who were more accurate but slower. This result suggest not only a difference in the demands games impose according to their genre but also a priming effect of these demands on the strategies used in consecutive tasks, such as a posttest. The speed demands of Game-like task 1 in the motion condition may have influenced players to become faster as the game required them to deploy motor skills and visual attention as they progressed in the trials. Therefore, it is possible that this action influenced the faster RTs obtained in the consecutive assessment task over the accuracy performance in the same task. The effects of motion tracking on declarative memory can only be specified at this point through the higher speed of recognition in the assessment task, which is a measure that has been mostly used in studies for assessing the improvement of cognitive skills (Liu & Watanabe, 2012).

In Experiment 2, players recognised prime numbers learned under the motion condition faster but at the same time they made more mistakes in the recognition. Speed-accuracy issues are common in the attentional tasks players are tested (Nelson & Strachan, 2009) after interventions. However, this experiment tested players' response times in the recall of the information learned during game play, i.e. in a memory task. McLeod and Nelson (1984) offered a different conception to the traditional interpretations of accuracy and RT for memory processes, establishing that despite their potential overlapping, the processes they measure are not identical. For the authors, accuracy of responses can be construed as a measure of "sufficient encoding for retrieval', while response time serves as a measure of the "number of decoding steps during retrieval before the item is output" (MacLeod & Nelson, 1984, p. 233). This distinction can be seen as a difference in the levels of processing of information and illustrates how insight into declarative memory formation could be elicited by these variables. A traditional assumption of the relationship between accuracy and response time refers to the sensitivity of the latter as it can continue to show differences between conditions, even if accuracy remains equal for both conditions, which is the case for the results in this experiment (Dye et al., 2009b; Colzato et al., 2010; Boot et al., 2008; Strobach et al., 2012; Cain et al., 2012). This finding can also be regarded positively in the understanding that despite a sufficient level of encoding (similar scores across conditions), there is a reduced number of decoding steps in the motion condition, which implies greater automaticity, understood for declarative learning as a greater development of fluent recall through overlearning. In other words, these findings show that tracking objects in motion does not have an effect on the degree of encoding of information since there is no difference in the accuracy of responses across conditions. However, motion tracking has influenced response times impliying reduced steps in the process of information retrieval, leading to greater automaticity which is the effect being captured by this measure.

The analysis of accuracy levels during game play showed that accuracy performance was influenced by the motion of objects despite the increased challenge. Using a single measure, i.e. only counting correct hits, both conditions showed a similar pattern of performance during game play. However, the use of a measure combining correct hits and correct misses showed that performance during motion game play reflected a higher rate of recognition, in spite of the game's difference in challenge compared to the static version. Therefore, more prime numbers were correctly remembered as the motion game progressed, suggesting an influence of the game features in attentional resources and working memory, which led to a higher recognition during game play. This result was similar to the one obtained in Experiment 1 and can be understood in terms of the theoretical concepts associated with visual attentive tracking, namely the deployment of attentional resources with the serial tracking of objects in motion and the interaction with working memory to maintain the binding of information and location.

Limitations can be identified in Experiments 1 and 2 that need to inform recommendations for the next experiments in this research. The observed limitations are related to the game design which lacked a more authentic context of video game play, irrespective of the required laboratory setting. Firstly, a change needs to be made to modify the current task that was contained in the two separate versions. A single change of conditions from motion to static or viceversa does not emulate a natural gaming situation, as it disrupts the flow of playing and predisposes participants into a sustained 'mode' for each condition. This could generate a bias when, for any reason, participants perceived one task as more difficult than the other. One way to solve this limitation is to compile both conditions into one single game task with trials alternating between conditions. Secondly, the current game used in this first experimental phase can be considered an initial design with the potential of development of certain features and outlook but maintaining the simplicity of the game mechanics in order to engage participants into playing it for a longer time in a single session. The incorporation of sound and visual effects were among the elements to be included that could contribute to a more authentic game-like experience, despite occurring in a laboratory setting. Thirdly, the current game evidenced a dispartity in time on task across conditions. Whereas both conditions contain trials of the same duration (25 seconds), the dynamics of the game, i.e. the run-time relationship between player and game mechanics (Hunicke et al., 2004) creates this difference due to the tracking of the target feature being required in only one of the games. The tracking of objects led to a longer trial and therefore a higher time on task than the static condition in which no tracking is needed, and responses can be made much quicker, leading to less time on task for players. Therefore, a mechanism that solved this issue needed to be developed for incorporation in the next gaming task. The incorporation of these modifications in a new game task (Game-like task 2) was guided by the understandings of game design and attentive tracking (full explanation in Chapter 4 (section 4.3.3.5.)). And finally, results from game play showed that there is higher accuracy while playing the motion game but this could not be observed in the assessment task. Experiment 1 suggested the inclusion of more questions in the assessment task which was adopted in the present experiment without any improvement in the results. The rationale was to provide more opportunities of recall in the assessment task. However, the format of assessment could also be related to this lack of transfer. Although evidence for the difference between the format of the assessment, either computer-based or paper-based, is not conclusive (Noyes & Garland, 2008; Porion et al., 2016), there is some evidence that paper-based testing leads to better performance (Chen et al., 2014; Jay et al., 2019). Therefore, a recommendation for future experiments is to test a different format for testing.

Another observed limitation is the reduced sample size used in the experiments which provided limited power in terms of statistical testing and extending interpretation of findings. Post-hoc and sensitivity power analyses were conducted with the results obtained to establish the power of the study with the given parameters and to establish the minimal detectable effect as a function of an ideal power of 1-ß = .80 (see Appendix VIII). These studies did not consider a monetary reward and therefore it was difficult to recruit people to be willing to participate, especially in consecutive sessions which were difficult to attend to without an incentive.

In sum, playing the game for a longer time had an effect on the recall of prime numbers in both conditions. However, despite means, both for response time and accuracy, being in the direction of the hypotheses, only response times – reflecting a faster recognition – seemed to be affected by tracking and acting on objects in motion. Accuracy scores were higher for those numbers learned in the motion game, but the difference with the static condition was not statistically significant. Issues with an underpowered design due to small sample sizes may influence this lack of conclusive evidence for the benefits of motion tracking in declarative memory formation.

5.4 Summary of the chapter

This chapter addressed two experiments of Phase 1 that sought to explore the question that tracking and acting upon objects in motion containing semantic information could lead to a more accurate and faster recall of such information than when objects remained stationary in a video game format. The two experiments used Game-like task 1 to test the hypotheses. Neither experiment provide evidence to support hypothesis H_1 relating the effect of tracking objects in motion to increased accuracy in a recall task. Some evidence from Experiment 2 provided support for hypothesis H_2, relating the effect of tracking objects in motion to faster recognition in a recall task. Therefore, the main research question of this study can only be partially answered with the experiments conducted in this phase. The lack of conclusive results was discussed in terms of the factors that may interfere with declarative memory formation through the tracking of objects in motion via video-game play, resulting in suggestions to modify aspects of the game design as well as the research design for future experiments, namely:

- The design of one gaming task that includes both conditions in a single application.
- The incorporation of more game-like features, e.g. more objects on screen, sounds, visual effects.
- The development of an algorithm to maintain the numbers on screen for an equivalent amount of time, regardless of the mechanics involved in the different types of trial (motion/static) during game play.
- The development of an alternative assessment task that is paper-based.

The next experimental phase addresses some of these limitations with three further experiments using a modified game task to test the hypotheses of this research. The modifications to be introduced in the next phase are aimed at designing a computer game with more game-like features, extended number of trials, additional corpora, and more objects on screen to encourage the tracking of multiple objects.

Chapter 6 Experimental Phase 2 – Exploring the effect of tracking of multiple objects in declarative learning

6.1 Overview of Experimental Phase 2

A second experimental phase was determined to denote the exploration of the research question with a more game-like task that arose as a result of the modifications suggested to the initial version of the game that stemmed from the previous experimental phase. Experimental Phase 2 consisted of three experiments that addressed the research question using a new game design, Game-like task 2 (see section 4.3.3.5 Game-like task 2), with variations for each of the studies presented in this chapter. Experiment 3 also served to test the new game design that included the recommended modifications listed in Chapter 5 and used different formats of assessment tasks to test whether there was a difference between computer-based and paper-based assessment tasks. Findings from Experiment 3 resulted in further modifications to the gaming task used in Experiment 4, that concerned the number of trials, the use of colours and feedback, and the use of visual occluders to enhance the gaming experience of the players. Finally, Experiment 5 explored the research question using this version of Game-like task 2 but in a two-player modality to test the hypotheses in an environment of social competition.

6.2 Experiment 3: Tracking multiple objects in motion

This was the first experiment that used the new version of the game for hypothesis testing as well as to check the game mechanics. The experiment also tested new corpora and different formats for assessing the learning.

Game-like task 2 was used in these experiments to explore the RQ:

RQ_{main} What is the influence of the movement of learning stimuli, tracked as part of an educational video game-like task, on the declarative memory of their properties, as measured by accuracy and speed of recall?

The following hypotheses were be explored to investigate learning through a motion-based computer game, in which individuals must track and act upon a moving target in order to respond:

H_1: Accuracy of responses will be significantly higher for numbers learned under the motion condition compared with those under the static condition measured by the difference between pre and posttest.

H_2: Response time will be significantly lower for numbers learned under the motion condition compared with those under the static condition measured by the difference between pre and posttest

Hypotheses H_1 and H_2 corresponded to the measure of learning and were answered through the analysis of the assessment task in the testing stage.

6.2.1 Participants

Seven male and twelve female participants were recruited for this experiment (*M* = 31.9 years of age, *SD* = 7.49) through snowballing from previous participants. All participants were university postgraduate students and took part on a voluntary basis and none of them had taken part in the previous experiments. They all had normal to corrected vision and were in a healthy condition at the time of the experiment.

6.2.2 Design

This experiment followed a within-participants pre-post-test experimental design. Participants were randomly assigned to distribution groups which also counterbalanced the order of conditions. Two DVs – RT and accuracy of learning – will be measured under two IVs – condition (two levels: motion/control).

Table 6.1
Group Distribution Design – Experiment 3

Group	Pretest		Corpus		Posttest	
	1	2	Motion	Static	1	2
1	computer	paper	C3	C4	paper	computer
2	paper	computer	C3	C4	computer	paper
3	computer	paper	C4	C3	paper	computer
4	paper	computer	C4	C3	computer	paper

6.2.3 Tasks and materials

Game-like task 2 (see Figure 4.10 and Figure 4.11) was comprised of both conditions in one single game by alternating the two types of trial corresponding to each condition. By default, the game started on a static trial. This was deemed an easier start of the game for the participants. For this experiment, the game featured 45 trials equivalent to nine loops (5 sets of numbers in each corpus) equivalent to 22 motion trials and 23 static trials. Each trial had a maximum duration of 25 seconds. The game had a maximum score of 450 points to be earned. The main task of identifying the prime number was maintained but the level of difficulty was increased as every trial depicted four numbers simultaneously on the screen, one target and four distractors.

Other features such as different colours and fonts (for the boxes containing the numbers) were included. In addition to the feedback windows previously featured, a visual and auditory explosion were included for successful trials prior to the feedback window appearance. For the unsuccessful trials, a beeping sound evocative of an error was emitted without any visual display but the negative feedback window (Figure 6.1). Corpus 3 and 4 were used with Game-like task 2 (Table 4.3).

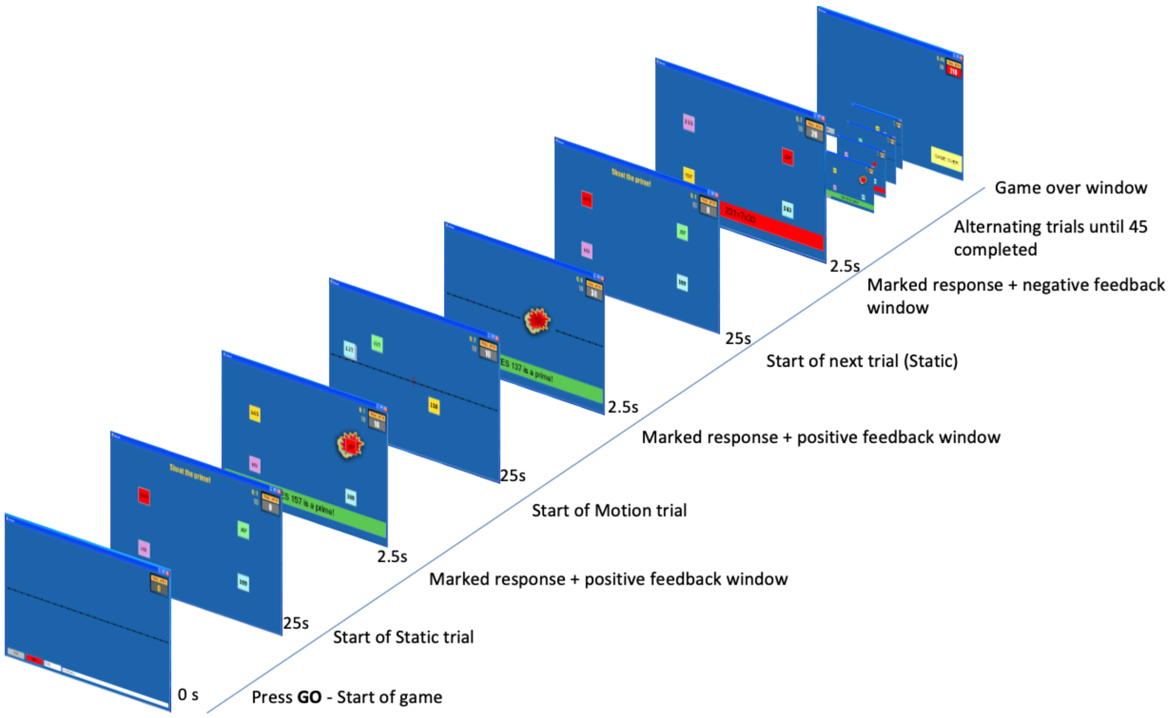


Figure 6.1. Sequence of screenshots in Game-like task 2 version used for Experiment 3. This gaming task consisted of 45 trials alternating the conditions (motion – static). There was positive and negative visual and auditory feedback after each trial. Each trial was displayed for 25 seconds and players used a labelled keyboard to mark their answers. A scoreboard indicated the points obtained after each trial.

The assessment task adopted both a paper-based and a computer-based format. A paper test was included to understand whether the format of testing presented a difference at the time of assessing learning after game play. The paper-based form consisted of a booklet with a question on each page exactly in the same format as in the computer version but participants had to mark with a pencil (Figure 6.2). Participants were given three minutes to answer as many questions as they could. The computer-form assessment task was also modified to be completed in three minutes with a maximum of 40 questions and the same 25 seconds maximum to provide a response. A consuming time bar was introduced to indicate the time left for the task (Figure 6.3). No feedback was provided in any of the test formats until the end of the experiment.

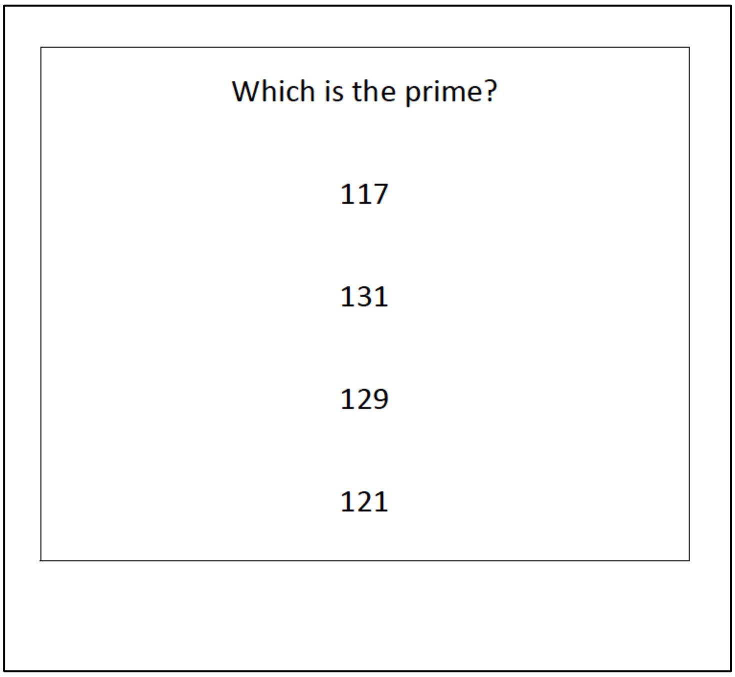


Figure 6.2. Example of paper-based assessment task. Numbers were presented in series of four and participants had to mark their responses with a pen before turning the page to the next question.

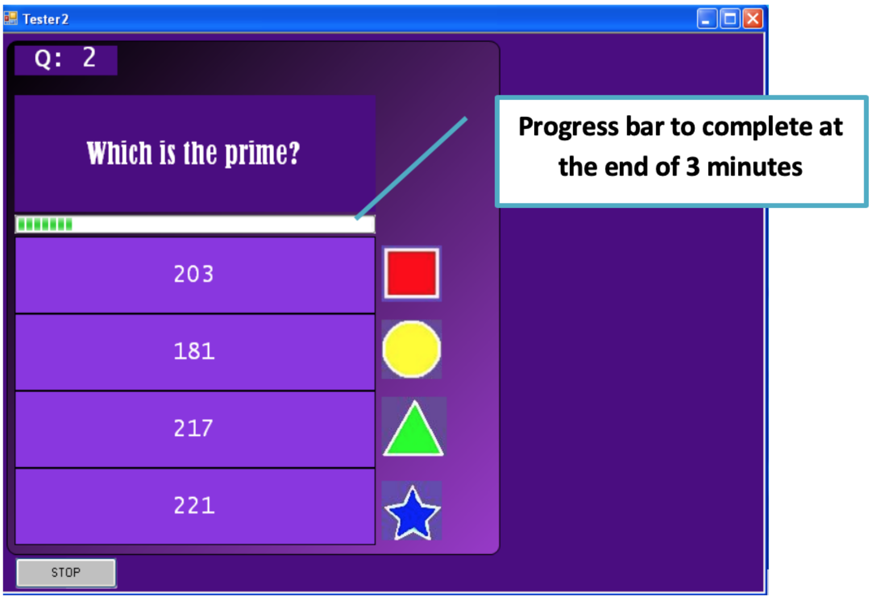


Figure 6.3. Screenshot of modified assessment task. This version allows three minutes in total to answer as many questions as possible. Participants mark their answers in a labelled keyboard. At the end of the three minutes, the task stops and no more questions are shown.

6.2.4 Procedure

Participants were invited to an individual session which was held in a dedicated computer laboratory. On arrival, they were briefed on the aims of the research and the number of tasks of the session, and invited to sign an informed consent form which contained the information explained plus their details if they agreed to participate (See Appendix II).

The first task to be undertaken was the pretest. This session required each participant to complete the assessment task in two formats (computer and paper). Participants were instructed in how the computer task worked and in the concept of prime numbers using a visual aid. The same was done with the paper-based task. Once the pretests were completed, participants were explained the game using visual aids with screenshots (Appendix IV). They were told that the game had 45 trials and they were also warned about the repetitive nature of the game in order to keep them on task. A board with previous pseudonyms and scores was visible to incentivise competition and active participation.

After the game play was finished, participants completed the posttest (identical to the pre-test) following the order established in the distribution table (Table 6.1). A brief anecdotal conversation was sustained at the end of the session to check for general insights about the game and their learning experience. Once all tasks were finished, participants were thanked for their participation and asked whether they had any further questions. Participation finished with a further contact through email (a few weeks later) to send their results in a score chart.

6.2.5 Results

Results were analysed considering all players' response times (for correct responses only) and performance accuracy from the assessment task as well as from game play. Mean data from the assessment task was converted to a percentage of accuracy and RT based on the duration of the task and they were used to respond to hypotheses H_1 and H_2. Table 6.2 shows the general descriptive statistics for accuracy and response time from the assessment task.

Table 6.2
Descriptive Statistics for Accuracy (%) and Response Time (%) – Experiment 3

	Motion			Static		
	Pretest	Posttest	Difference	Pretest	Posttest	Difference
Accuracy						
N	19	19	19	19	19	19
Mean	34.20	55.71	21.51	33.25	49.43	16.18
Std. Deviation	16.10	19.65	20.75	20.51	19.04	21.38
Minimum	12.5	0	-20	0	17.65	-19.23
Maximum	60	90	77.5	85	92.86	61.11
Response time						
N	19	19	19	19	19	19
Mean	49.56	48.57	-0.99	50.04	43.60	-6.43
Std. Deviation	10.09	8.73	13.88	11.20	8.38	15.06
Minimum	22.69	36.19	-23.15	36.3	24.61	-44.31
Maximum	65.45	70.73	34.33	87.22	55.31	12.68

6.2.5.1 Hypotheses H_1 and H_2

Preliminary analysis using K-S test showed the distribution of the sample data was normal for both accuracy, $D(18) = .215$, $p = .200$ and response time, $D(18) = .210$, $p = .200$. This allowed the use of parametric tests.

Accuracy – H_1

Figure 6.4 depicts the mean difference between pre and posttest for accuracy in each condition. A smaller mean difference for accuracy was observed in the motion condition (M = 21.51; SD = 20.75) compared to the static condition (M = 16.18; SD = 21.38) (Table 6.2). This difference of 5.33%, however, was not statistically significant as shown by a paired-samples t-test, $t(18) = -.835$, $p = .415$, $d = 0.19$, 95% CI [-8.1, 18.73]. Therefore, hypothesis H_1 that prime numbers would be better recalled when learned under the motion condition as compared to the static cannot be supported. The tracking of objects in motion did not have an effect on declarative learning as no difference could be established between the conditions as measured by accuracy of recall.

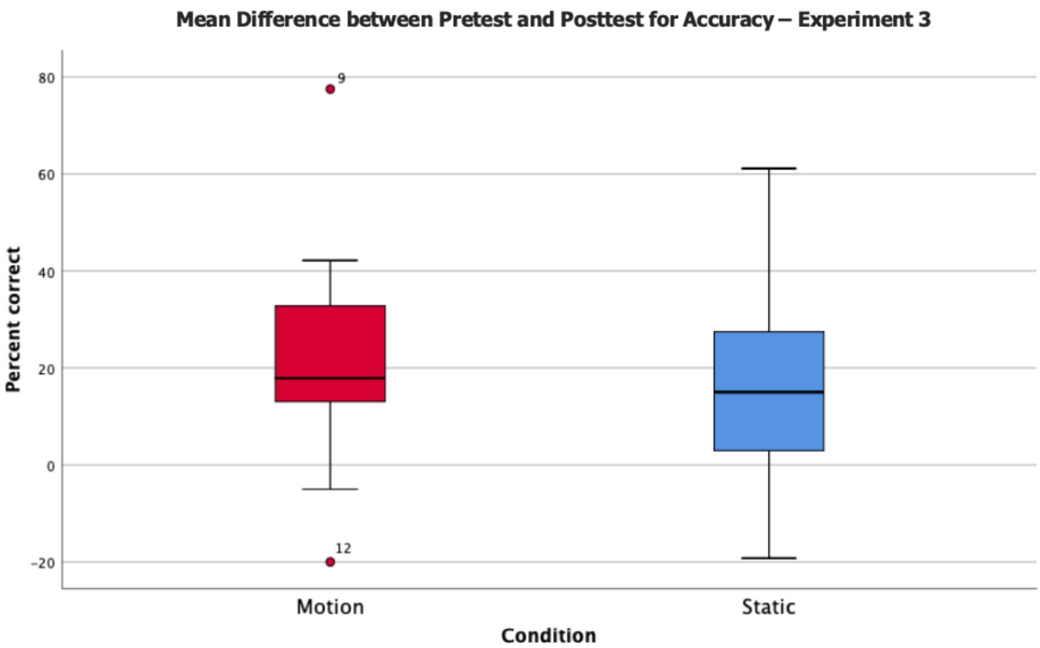


Figure 6.4. Mean difference in accuracy between conditions in Experiment 3. A percentage of the scores was calculated per participant and a mean difference between pre and posttest was obtained per condition.

Response time – H_2

A difference in RTs was observed between the mean difference for the motion (M = -.99, SD = 13.88) and the static (M = -6.43, SD = 15.06) conditions. In this case, it was the static condition with faster recognition. However, this difference between conditions was not statistically significant, $t(18) = 1.04$, $p = .311$, $d = 0.24$, 95% CI [-5.53, 16.41]. This evidence cannot reject the null hypothesis and therefor there is no support for hypothesis H_2, motion tracking does not make a difference in the faster recognition of semantic information compared with a static scenario.

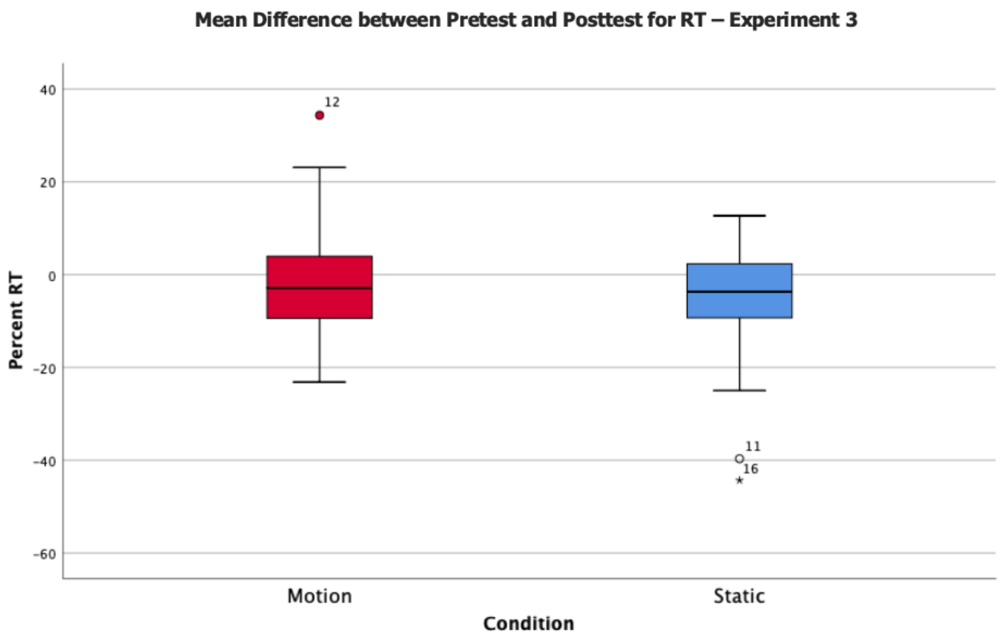


Figure 6.5. Mean difference in response time between conditions in Experiment 3. Response time values are shown as a percentage of the total RT for responding the the pretest and posttest in 3 minutes.

6.2.5.2 Additional analyses – Game play and corpora analysis

Game-like task 2 in Experiment 3 - Accuracy

Game play in Experiment 3 had an average duration of 9.29 minutes (*SD* = 2.67) to complete a total of 45 trials between the two condition (Static: *N* = 23; Motion: *N* = 22). For the analyses, only the correct responses were considered. Table 6.3 contains a summary of the descriptive statistics for each condition.

Table 6.3
Summary of Descriptive Statistics for Game Play Performance - Experiment 3

	Motion		Static	
	Accuracy	RT	Accuracy	RT
N	22	22	23	23
Mean	6.95	9.67	7.70	6.82
Std. Deviation	2.19	1.82	1.77	1.51
Minimum	3	5.85	4	3.5
Maximum	12	13.34	11	10.38

The number of correct responses per trial and condition was counted for establishing the accuracy level during game play. *Figure 6.6* shows the relationship of accuracy as the game progresses. The static condition shows a strong positive correlation that is significant (**Error! Reference source not found.**). The difficulty of the motion trials is evident from the plot as there is a fall in the accuracy halfway through the game, showing a very different game play experience in the two conditions. This difference in accuracy between conditions is not statistically significant, $t(21) = -1.19$, $p = .246$, $d = 0.26$, 95% CI [-1.87, .506].

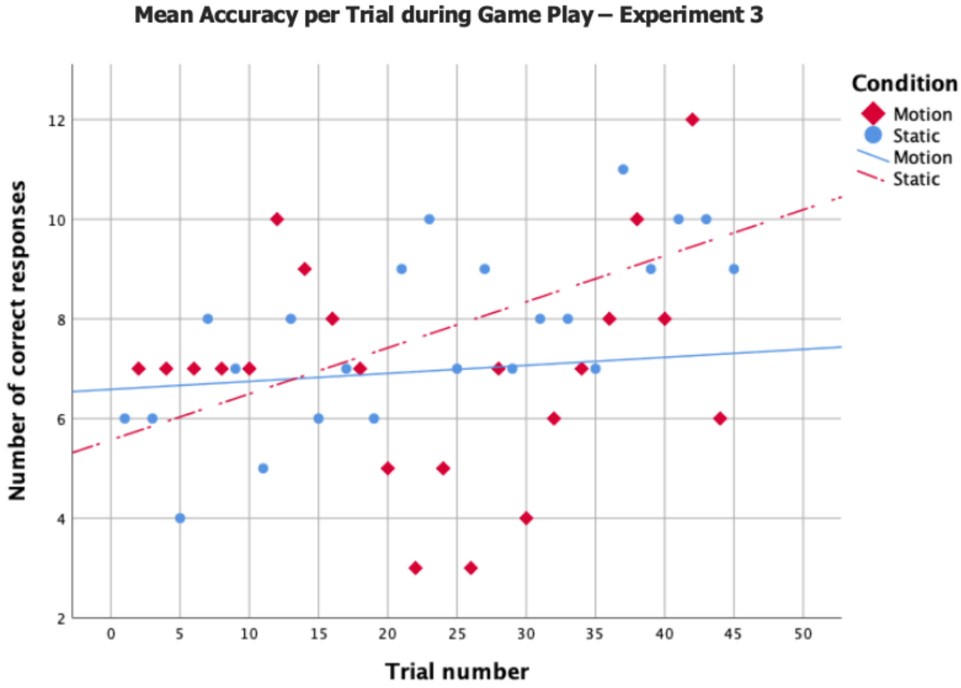


Figure 6.6. Mean accuracy per trial during game play in Experiment 3. A mean of the correct responses was calculated per trial per participant and shown per trial number. Trials are alternate and the game begins with a static trial by default.

Corpora analysis

Of the possible total of 450 earnable points, the maximum score achieved during game play was 260 and the mean score was 185, equivalent to 41.1% average performance. Table 6.4 shows the percentage of performance for the prime numbers which appeared in corpora 3 and 4. Primes appeared on average 85.5 times (*SD* = 6.77) and the average performance was 40.26% (*SD* = 11.16). There is a balance in corpora as there are numbers highly recalled while others are more problematic, perhaps due to confusion with distractors in the similar range. Half of the primes are above the average performance value.

Table 6.4
Corpora Performance During Game play – Experiment 3

	131	149	181	193	379	127	163	179	191	373
Number of times appeared	78	82	95	91	82	94	88	76	80	89
Number of CH	44	23	50	33	24	26	37	41	35	29
Performance (%)	56.41	28.05	52.63	36.26	29.27	27.66	42.05	53.95	43.75	32.58

6.2.6 Discussion of Experiment 3

This first experiment of Phase 2 used Game-like task 2 which included more game-like features than Game-like task 1 to enhance the player's experience and rely on more authentic game play. This had the purpose of maintaining engagement to keep players on task in both conditions and to test the experimental hypothesis with a task presenting more objects on screen, sounds and visual effects and that contains both conditions embedded in a single game. Despite these modifications, no evidence was found for the influence of motion tracking on declarative memory in this experiment.

Compared to Game-like task 1, Game-like task 2 involved more objects on screen in order to bring more attention about through the random movement of objects and the need for tracking them. This motion made objects appear in different degrees of proximity or change their direction swiftly at times and this effect produced the deployment of more attention for updating the target locations (Tombu & Seiffert, 2008). This might have also taxed players' cognitive load due not only to the number of objects that needed to be attended to and their changing locations but also in respect of their semantic information in order to complete the game's goal. This increment in load occurred for the two conditions, but tracking and catching the moving number was perceived as more difficult among players as per spontaneous comments made after the game was over.

Interestingly, the results from the assessment task showed that mean difference scores of the motion condition were slightly higher than the static condition, but the difference was not enough to establish statistical significance. The assessment task also showed its capability to detect a change after game play for both conditions, which eliminates the possibility of an imbalance in the level of difficulty between the trial type. This experiment considered using a paper-based testing in parellel to the computer-based task that has been used so far. This was based on findings by Jay et al. (2019) in which school students responded better to a paper-based task compared to a computer-based one after an intervention using computer games to learn maths. However, the results from Experiment 3 showed no difference between paper or computer for accuracy which is in line with previous research reporting no difference between these media of assessment (Noyes & Garland, 2008; Porion et al., 2016). One drawback from the use of paper-based tasks is the difficulty to measure response time for individual stimuli. The use of a paper-based pre and posttest was then discarded for future experiments.

The alternation of trials in Game-like task 2 may provide a better flow to the game but may still not be enough to achieve learning. The number of trials was increased to 45 in total in this experiment, which was a difference compared to Game-like task 1 in terms of the total number of trials per game, as Game-like task 2 contained both conditions in one task. However, it was not a very big difference in terms of number of trials per condition, as Experiment 1 had 15 trials for each condition. Experiment 2, conducted over five days with 20 trials per condition saw an effect of motion in learning, suggesting that time of exposure to the game was relevant. One modification for the next experiment would be to extend the number of trials to 100 to provide more chances of exposure to the game which would enable players to earn scores and develop a sense of mastering the game which may play a role in their engagement with the task.

The aesthetic components of the game (e.g. different colour for the boxes with numbers, different fonts, bright-coloured background) made it more colourful, with the aim of engaging attention to the game and to ressemble more real games' palettes. Makovski and Jiang (2009b) suggested that an object's surface properties can be stored in visual working memory while being tracked and the use of objects in unique colours would enhance such tracking. However, the fact that each box contained a different colour may have interfered with the attention deployed to the unique identities of the boxes, so it was decided to eliminate the colour and leave all boxes in black for the next experiment.

Another modification of the task to be used in the next experiment is related to the use of occluders in the form of walls to encourage the deployment of working memory and enhance recall. Thus, in the motion trials, the numbers would disappear behind these walls momentarily and this would require players to hold the information of the likely reappearance of the object in their working memory, which hypothetically would encourage the recall while tracking.

Results from this experiment provided no evidence for supporting the notion that tracking and acting over objects in motion in a learning video game task may enhance declarative memory. However, there are indications of learning in the gaming task, and the assessment task was able to detect a difference between pre and posttest after game play. There are elements around the game design to be modified for the next experiment. The first is the extension of the duration of the game by increasing the number of trials to 100 based on the results from Experiment 2 that illustrated the trajectory of the effect of the conditions in time on the learning of a mathematical fact. A second modification would be to eliminate the written feedback from the screen and leave it to a graphical and auditory display only to foster the flow of the game and still provide feedback on the type of responses. A third modification relates to the use of a unique colour for the objects on screen to avoid associating them with their features instead of their semantic information. A fourth change to Game-like task 2 is the inclusion of occluders to make numbers disappear from the visual field for brief spans to promote the use of working memory on players during game play. These modifications are expected to give a more game-like aspect to Game-like task 2 and provide players' with a more authentic game play experience.

6.3 Experiment 4 – Individual game play

This experiment aims to test the modifications made to Game-like task 2 which stemmed from results and observations from the previous experiment. The refining of the game task aimed to provide more time of exposure to the game in one session to encourage the encoding of semantic information via motion tracking of objects with unique colour and maintaining distinct semantic identities, and to foster the use of working memory via the use of visual occluders that impair the visualisation of objects for brief moments. This experiment sought to explore whether players remember more and faster those prime numbers learned under a motion condition compared to a static one. Response times and accuracy of responses continued to be the dependent variables representing learning. The independent variable again corresponded to the condition in two levels: motion and static.

Game-like task 2 was used in these experiments to explore the RQ:

RQ_{main} What is the influence of the movement of learning stimuli, tracked as part of an educational video game-like task, on the declarative memory of their properties, as measured by accuracy and speed of recall?

The following hypotheses were be explored to investigate learning through an motion-based computer game, in which individuals must track and act upon a moving target in order to respond:

H_1: Accuracy of responses will be significantly higher for numbers learned under the motion condition compared with those under the static condition measured by the difference between pre and posttest.

H_2: Response time will be significantly lower for numbers learned under the motion condition compared with those under the static condition measured by the difference between pre and posttest.

Hypotheses H_1 and H_2 corresponded to the measure of learning and were answered through the analysis of the assessment task in the testing stage.

6.3.1 Participants

This experiment recruited fifty participants (36 females, 14 males) whose average age was 32.32 years old (*SD* = 9.84). They were students at a university in England from different course and degrees. They all had normal to corrected vision and were in a healthy condition at the time of the experiment. One participant's data was finally eliminated for not responding to the posttest. Therefore, the sample for this experiment was *N* = 49.

6.3.2 Design

This experiment followed a within-participants pre-post-test design. Participants were randomly assigned to distribution groups (Table 6.5) to counterbalance the allocation of the corpora to the conditions. Two DVs – RT and accuracy of learning – were measured under two IVs – condition (two levels: motion/control).

Table 6.5
Group Distribution Design – Experiment 4

Group	Pretest	Corpus		Posttest
		Motion	Static	
1	x	C3	C4	x
2	x	C4	C3	x

6.3.3 Task and materials

The same assessment task as in Experiment 3 was used in this experiment. Players were asked to identify prime numbers shown in a multiple choice question in a total time of three minutes with each question being presented for 25 seconds (Figure 6.3).

The gaming task used was Game-like task 2 with corpora 3 and 4 (Table 4.3) allocated alternatively to each condition within the game. The game included visual occluders in the form of walls behind which the numbers would disappear briefly in the motion condition (Figure 4.10). This modification was adopted to promote the effort of maintaining information in working memory and increase the possibilities of a better recall. Figure 6.7 shows a sequence of the screenshots for Game-like task 2. The time for showing the feedback window follows an algorithm for maintaining the information on screen for the same amount of time for both conditions. This was done by keeping a running total of the overall timings per trial and subtracting it in the next corresponding trials.

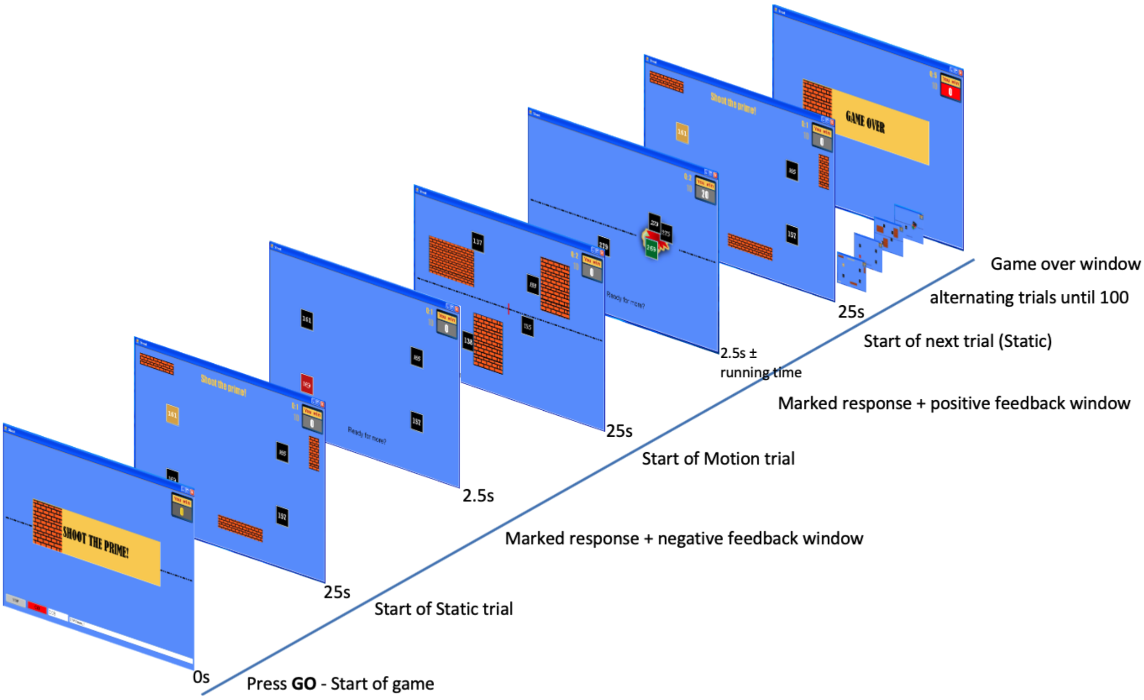


Figure 6.7. Sequence of screenshots for Game-like task 2 used in Experiment 4. This gaming task consisted of 100 alternating trials (motion – static). Walls acting as occluders were included in this version of the gaming task to foster working memory. A positive or negative visual and auditory feedback occurred after each trial but without the legend indicating the mathematical calculation as in the previous version. Each trial had a duration of 25 seconds and players used a labelled keyboard to mark their answers. A scoreboard indicated the points obtained after each trial.

6.3.4 Procedure

The procedure followed that of Experiment 3 with one exception that there was no instruction for a paper-based pre and posttest (see page 121). See Appendix II for further details on informed consent and Appendix IV for the corresponding instructions provided to participants (Game-like task 2 in Experiment 4).

6.3.5 Results

Results were analysed considering all players' response times (for correct responses only) and performance accuracy from the assessment task as well as from game play. Mean data from the assessment task was converted to a percentage of accuracy and RT based on the duration of the task and they were used to respond to hypotheses H_1 and H_2. Table 6.6 presents general descriptive statistics for accuracy and response time from the assessment task.

Table 6.6
Descriptive Statistics for Accuracy (%) and Response Time (%) – Experiment 4

	Motion			Static		
	Pretest	Posttest	Difference	Pretest	Posttest	Difference
Accuracy						
N	49	49	49	49	49	49
Mean	29.06	46.25	17.18	30.55	50.68	20.13
Std. Deviation	21.51	16.62	25.72	17.75	16.84	22.29
Minimum	0.00	18.18	-34.55	0.00	20.00	-46.67
Maximum	75.00	84.62	72.12	75.00	90.00	75.00
Response time						
N	49	49	49	49	49	49
Mean	54.06	42.54	-11.53	51.74	44.10	-7.64
Std. Deviation	10.95	9.49	15.13	12.82	8.22	15.44
Minimum	30.15	20.36	-42.71	2.68	24.68	-41.59
Maximum	83.64	68.94	31.56	82.97	59.90	37.77

6.3.5.1 Hypotheses H_1 and H_2

At a descriptive level, results show that numbers learned in the static game were better recalled in the posttest than those learned in the motion game. However, players seemed to recognise faster those numbers learned in the motion condition, which means players were able to recognise prime numbers learned in the motion trials faster but at times they failed to be accurate.

Accuracy – H_1

Figure 6.8 depicts the mean difference between pre and posttest for accuracy in each condition. The medians are almost the same for both conditions, but the motion condition showed a more balanced distribution without many outliers as in the static condition. Preliminary analyses showed that the data was normally distributed for the variable of accuracy, $D(49) = .073$, $p = .200$. Therefore, parametric test was used for inferential statistics. Smaller mean difference scores for accuracy were observed in the motion condition ($M = 17.18$; $SD = 25.72$) compared to the static condition ($M = 20.13$; $SD = 22.30$). This difference of 2.95%, however, was not statistically significant as shown by a paired-samples *t*-test, $t(48) = -.637$, $p = .527$, $d = 0.09$, 95% CI [-12.23, 6.35]. Therefore, hypothesis H_1 that prime numbers will be better recalled when learned under the motion condition as compared to the static cannot be supported. The tracking of objects in motion did not have an effect on declarative learning as no difference could be established between the conditions as measured by accuracy of recall.

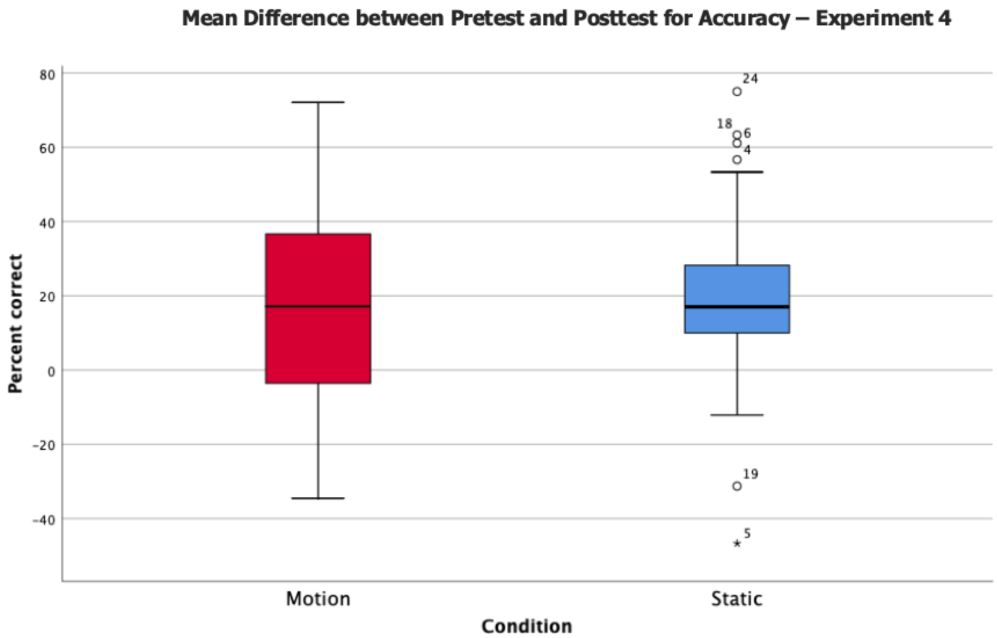


Figure 6.8. Mean difference between pre and posttest for accuracy in Experiment 4. A percentage of the scores was calculated per participant and a mean difference between pre and posttest was obtained per condition.

Response time - H_2

Figure 6.9 shows the mean difference in RT between conditions. Whereas the medians are similar between conditions, the distribution shows that the motion condition tends to have lower mean RTs than the static condition. A K-S test indicated that the distributions of the data for the variable RT was normal, $D(49) = .095$, $p = .200$, allowing the use of parametric tests. The motion condition showed a higher mean speed in recognition ($M = -11.53$; $SD = 15.14$) than the static condition ($M = -7.64$; $SD = 15.44$). This 3.9% difference is, however not statistically significant as shown by a paired-samples *t*-test, $t(48) = -1.43$, $p = .159$, $d = 0.20$, 95% CI [-9.34, 1.58]. Therefore, hypothesis H_2 that prime numbers are recognised faster when they are learned under a motion game cannot be supported. The tracking of objects in motion did not have an effect on declarative learning as measured by faster response times.

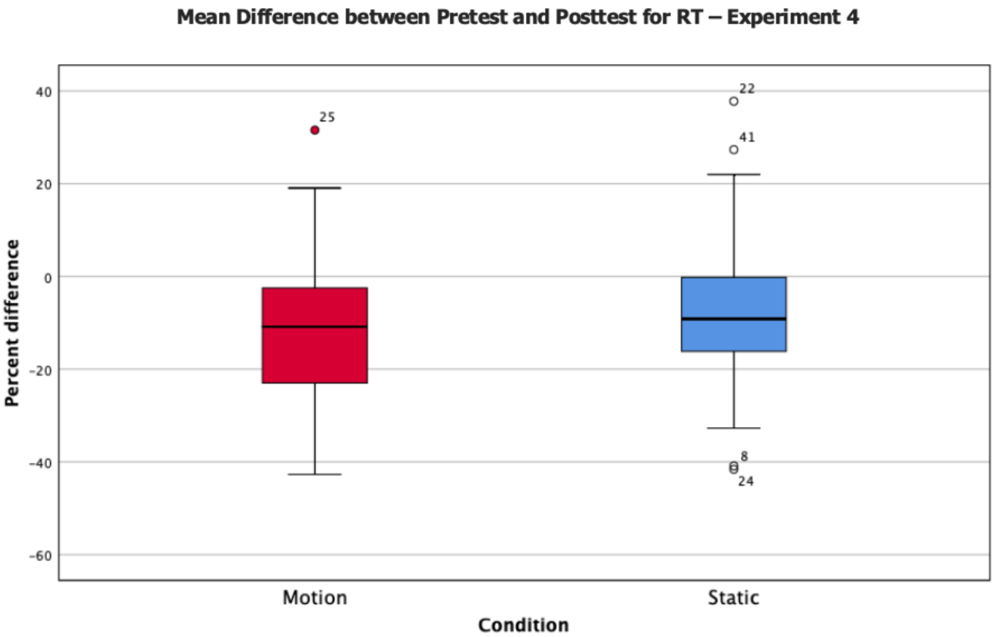


Figure 6.9. Mean difference between pre and posttest for response time in Experiment 4. Response time values correspond to a percentage of the RT per participant per condition.

6.3.5.2 *Additional analyses – Game play and corpora analysis*

Game-like task 2 in Experiment 4 - Accuracy

Game play in Experiment 4 had an average duration of 20.47 minutes (*SD* = 3.28) to complete a total of 100 trials divided equally for each of the condition (Static: *N* = 50; Motion: *N* = 50). This was 11.8 minutes more than in Experiment 3. For the analyses, only the correct responses were considered. Table 6.7 contains a summary of the descriptive statistics for each condition.

Table 6.7
Summary of Descriptive Statistics for Game Play Performance – Experiment 4

	Motion		Static	
	Accuracy (%)	RT	Accuracy (%)	RT
N	50	50	50	50
Mean	40.20	8.62	39.04	6.65
Std. Deviation	8.59	1.18	8.91	0.93
Minimum	24.00	6.27	22.00	4.41
Maximum	60.00	11.56	62.00	8.91

The number of correct responses per trial per participant was converted into a percentage of performance per trial. Figure 6.10 shows the mean accuracy of responses for each condition plotted against the trial number. In both conditions, players seemed to increase their correct responses as the game progressed in trial number.

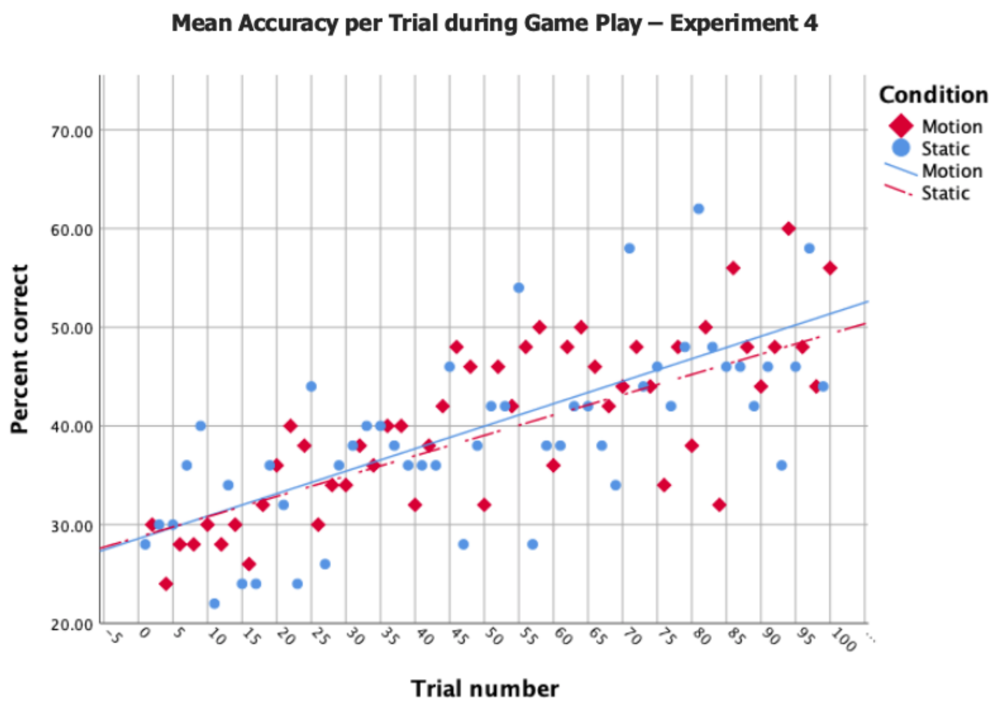


Figure 6.10: Accuracy per trial during game play in Experiment 4. Mean correct responses per trial is shown to illustrate the increment in recognition of prime numbers with the progression of trials in the game-like task. Trials are alternate and the task begins with the static trial by default.

Corpora analysis

Accuracy data during game play was also relevant to analyse the corpora used for this experiment. Table 6.8 shows the detail for accuracy performance of the prime numbers used. The highest rate of recognition is around 50% and the lowest is below 30%. Primes appeared on average 500 times (*SD* = 15.2) and the average performance was 39.74% (*SD* = 7.97). In this analysis, no clear relationship can be observed between being a smaller prime and the rate of recognition as with the previous two corpora used in Phase 1. It was previously suggested that more exposure to the task through extended play might increase recognition of primes which happened in Experiment 2 with increased game play time. This rate of response is still high for one session compared to the rate of recognition in Experiment 1 in which the time of exposure was considerably shorter in a single session.

Table 6.8
Corpora Performance During Game Play – Experiment 4

	131	*149*	*181*	*193*	*379*	*127*	*163*	*179*	*191*	*373*
Number of times appeared	485	511	510	514	480	515	488	490	487	520
Number of CH	248	147	197	224	227	153	157	173	212	246
Performance (%)	51.13	28.77	38.63	43.58	47.29	29.71	32.17	35.31	43.53	47.31

6.3.6 Discussion of Experiment 4

Experiment 4 largely replicated Experiment 3 with some modifications made to Game-like task 2's features concerned with appearance, such as the elimination of distinctive colours in targets and distractors to avoid their association to physical features (colours) rather than their semantic feature (content). The task also extended its trials to 100, which gave each condition 50 alternating trials and more game play time for players in a single session. The use of visual occluders in the shape of walls were added to the design in order to promote working memory and enhance recall. The data showed that players became better at identifying primes across trials during game play, but this level of identification was equal for both types of trials, suggesting that the feature of motion tracking did not make a difference in declarative memory formation, but that the game task has a learning effect. Similarly, the assessment task showed no difference in learning between the conditions. Therefore, there is no evidence for supporting the notion that tracking and acting over objects in motion in a learning video game task enhances declarative memory.

The lack of evidence from this experiment suggests that the task might not be sensitive enough to detect an effect and there might be other elements of video games that may need to be included. For the aim of the present research, the design of both Game-like task 1 and Game-like task 2 deliberately involved a minimum of features, as the purpose of the studies was to test the feature of motion tracking on declarative learning solely. Some of the basic elements suggested for games by Malone and Lepper (1987) in their taxonomy of intrinsic individual motivations were incorporated in the game task, i.e. challenge and feedback. These act as core elements for the engagement with the task and for reinforcing or modifying behaviours oriented to overcome the challenges. In the present research, the element of challenge has been provided first, through algorithms modulating the speed of motion and the time on screen to adapt the challenge according to the player's behaviour, and second, by adding more elements to be tracked as part of the game.

However, there are also essential elements of video games that fall within the category of interpersonal motivation, i.e. that have a dependency on other individuals, such as competition and cooperation (Malone & Lepper, 1987). Vorderer et al. (2003) associate competition in a game with the enjoyment and preference for playing it, which may in turn be beneficial if the game entails a learning objective. In the present research, cooperation was not considered within the game design, but the element of competition has been included as a personal scoreboard on screen as part of the game design to show players a track of their progress. Scoring systems have been traditionally included in the design of video games to foster motivation as they represent the action of accumulating goals while avoiding errors, which can in turn foster a rewarding behaviour via comparison and competition to measure one's own performance (Toups et al., 2009). Additionally, competition was included as part of the gaming environment by displaying a physical scoreboard with the pseudonyms and scores of previous participants in the room where they played the game.

The possibilities of instilling competition through video game play transcend the scoring system as games themselves can be conceptualised as a sequence of situations capable of enabling competition. A standard game play would generally offer the player situations that pose a specific need for action (e.g. to monitor and track numbers); situations that require a player to do something in order to resolve such need for action (e.g. to identify a prime number among distractors and wait for the number to near the aim and click on it); and situations that offer a result from such taken action (e.g. feedback received on the response given) that consequently influences both the sense of enjoyment and the understanding of future situations that require action (Vorderer et al., 2003). In this sense, the situations offered by Game-like task 2 to instil competition in players were present, but they rather represented an understanding of competition related to the individual challenge of mastering different tasks during game play, i.e. competition between the player and the computer (Alessi & Trollip, 2001), focusing mainly on the competitive elements involved in the game design (Vorderer et al., 2003).

Group play is another form in which the concept of competition can be understood in video game play (Fisher, 1976). As a naturally-occurring phenomenon, many computer games have been played in pairs or collectively, i.e. a social situation drives the concept of competition, what Vorderer and colleagues (2003) calls *social competition*. Lisón and colleagues (2015) found that when children and adolescents played an active video game in a competition format, i.e. with others, their affect and arousal were enhanced compared to when they played individually. For the researchers, the positive emotions arising from an increased pleasurable experience triggered by competition can lead to a more positive association with exercise. Furthermore, Cagiltay et al. (2015) found that when adding the feature of competition to a drill-and-practice video game, it increased the motivation and learning of participants and such higher motivation correlated with higher accuracy in the game. This indirect relationship between group competition and learning via motivation is a factor of the gaming environment worth exploring in the following experiment. Hence, an additional modification to Game-like task 2 will allow it to generate a scenario for 2-player mode as the element of competition to study the effect of motion tracking on declarative learning in a social competition environment.

Video games involve a variety of elements that add to the complexity of their mechanics which is expressed in a myriad of possibilities of game play methods and strategies for every single player. Despite the effort of including game-like features to both Game-like task 1 and 2, they still remain not a 'real' game as some elements have been omitted or minimised in order to isolate the main feature intended to be studied. For example, most off-the-shelf video games feature uncertain scheduling of rewards, i.e. a system of rewards that cannot be guessed and keeps the expectation of the player, or narratives embedded in the game that frames the goal of the game. Some of these features have also been studied by their effects on learning (e.g. rewards, see, Howard-Jones & Jay, 2016; Mason et al., 2017; Prena et al., 2018). Therefore, their addition would have confounded the main feature intented to be explored in this research. In order to avoid that, these typical elements in video games become extraneous factors that are necessary to avoid.

This leads to a further question about the actual possibility of reducing an educational gaming experience to elements and processes that can be studied in ways that exclude extraneous factors for the benefit of the experiment while maintaining the authenticity of the task for the benefit of the experience being studied. This reductionism is one of the challenges posed by research in educational neuroscience (Varma et al., 2008) through the need of conducting paradigmatically fixed experiments for studying phenomena of the social world.

6.4 Experiment 5 – Social game play

Based on the results and discussion from Experiment 4, the present experiment explored the research question in a game play environment involving social competition. In order to provide the competition environment, the version of Game-like task 2 used in Experiment 4 was modified to a player v/s player interaction pattern (Fullerton, 2019), in a face-to-face competition format, i.e. two competitors sitting next to each other in front of the same game (Yu, 2003).

Each of the previous experiments have applied modifications to the gaming or assessment task to adjust the sensitivity for detecting the effect of tracking objects in motion on declarative memory. This modification is added to the environment of game play in order to encourage social competition and as part of a more authentic educational scenario.

Using the modified version of Game-like task 2 for two players, this experiment aimed to explore the main RQ:

> ***RQ_$_{main}$* What is the influence of the movement of learning stimuli, tracked as part of an educational video game-like task, on the declarative memory of their properties, as measured by accuracy and speed of recall?**

The following hypotheses were be explored to investigate learning through an motion-based computer game, in which individuals must track and act upon a moving target in order to respond:

> ***H_1: Accuracy of responses will be significantly higher for numbers learned under the motion condition compared with those under the static condition measured by the difference between pre and posttest.***
>
> ***H_2: Response time will be significantly lower for numbers learned under the motion condition compared with those under the static condition measured by the difference between pre and posttest***

Hypotheses H_1 and H_2 corresponded to the measure of learning and were answered through the analysis of the assessment task in the testing stage.

6.4.1 Participants

Fifty-two participants (37 females, 15 males) were recruited for this experiment via posters and word-of-mouth. They were all university students in different faculties and programmes at a British university. Participants averaged 30.9 years old (*SD* = 7.29). They all had normal to corrected vision and were in a healthy condition at the time of the experiment. One participant did not complete the posttest so was removed from the sample, *N* = 51.

6.4.2 Design

The experiment followed a within-participants pre-post-test experimental design. Pairs of participants were randomly assigned to distribution groups (Table 6.9) to counterbalance the allocation of the corpora to the conditions. Two DVs – RT and accuracy of learning – were measured under two IVs – condition (two levels: motion/control).

Table 6.9
Group Distribution Design – Experiment 5

Group	Pretest	Corpus		Posttest
		Motion	Static	
Pair 1	x	C3	C4	x
Pair 2	x	C4	C3	x

6.4.3 Tasks and materials

A modification to the code was made in order to create a player v/s player interaction pattern, i.e. two players competed directly within the same game-like task and in the same room. Each player had their own screen (showing the same gaming task for both), their own controls through a labelled keyboard as used in previous experiments (Figure 4.9), and their own assigned colour to identify themselves on the screen. The scoreboard showed the points for each player. Additionally, each screen was labelled on top with their corresponding colour banner and the number of player (P1 = yellow; P2 = cyan). Players were sat next to each other divided by the computer tower and facing their corresponding screen. In the motion trials, there were two central aims (vertical lines in the middle of the screen) in the corresponding colour, so players knew their location on the screen. For the static trials, an additional square was added to the boxes containing the numbers on each side which was highlighted with every key stroke from the arrow-labelled keys in the corresponding colour for each player (Figure 6.11).

A) Static trial B) Motion trial

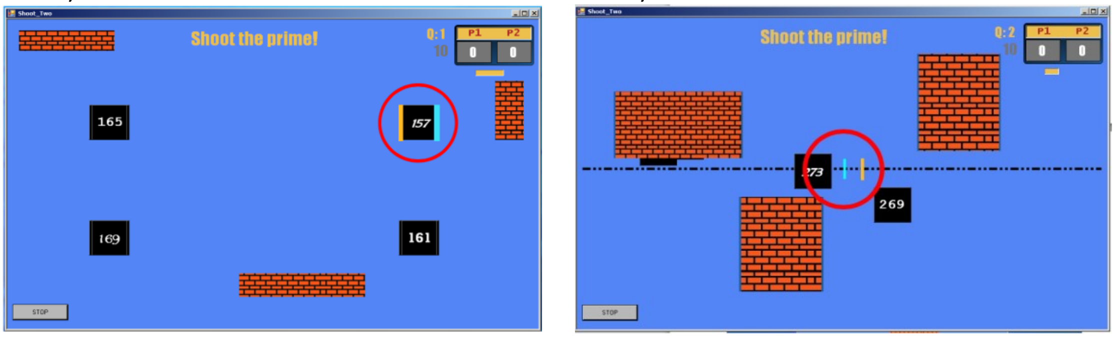


Figure 6.11. Game-like task 2 screens indicating how the colours are displayed for each player in the 2-player version of the task: yellow for player 1 and cyan for player 2. Each trial screen is simultaneously played and players need to compete for the numbers. Panel A) shows a screen for a static trial in which players change their position using a labelled keyboard. Panel B) shows a screen for a motion trial in which players move the central aim to the left or right using the keyboard. Numbers need to pass through the mid-line in order to be marked as a response. The scoreboard shows each player's scores after each trial.

The mechanics of the game were the same in the previous experiment (3 and 4). Responses (correct, incorrect and timeouts) were assigned to the first who marked the answer. Only correct responses earned points which were visible for both players. On screen, the difference from previous versions was in the colours used to identify each player. The game started with the static trial and had 100 trials to be completed, 50 for each condition (Figure 6.12). Participants were informed about that and the number of trials was indicated on the screen. This alleviates the pressure of not knowing how long to finish or to check whether they can beat their opponent.

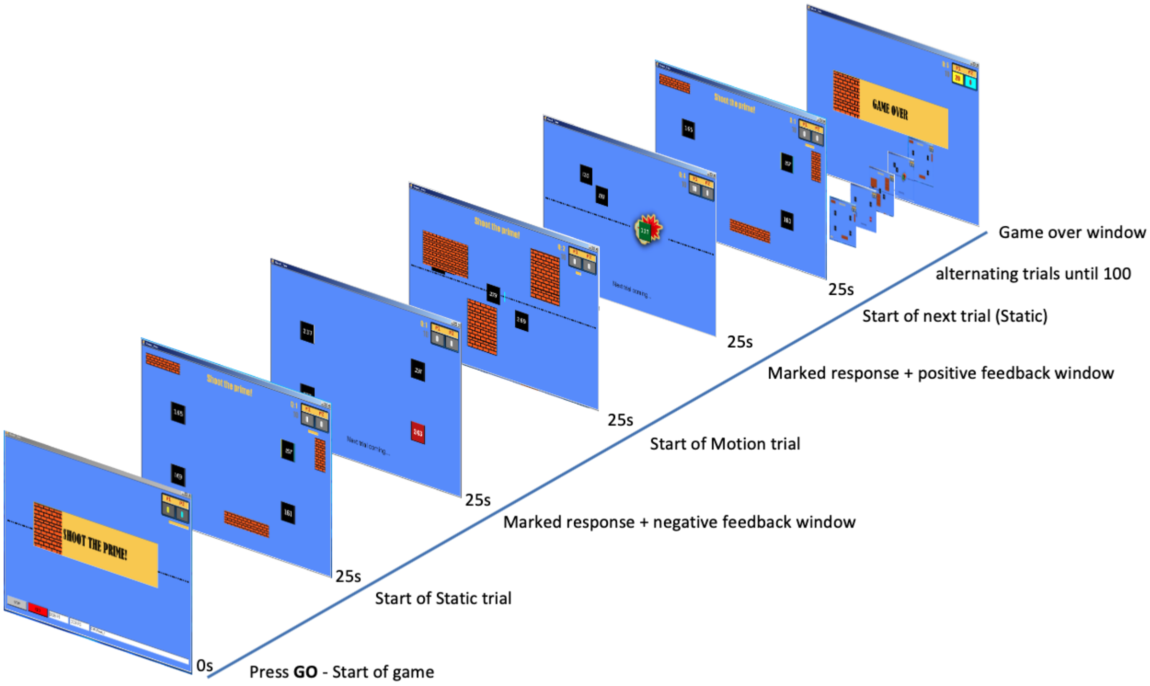


Figure 6.12. Sequence of Game-like task 2 two-player version used in Experiment 5. This gaming task consisted of 100 alternating trials (motion – static). Each player was assigned a colour so they can identify their position on the screen. The features of the version used in Experiment 4 were maintained. Each trial had a duration of 25 seconds and players used each a labelled keyboard to mark their answers. A scoreboard indicated the points obtained after each trial for each player.

6.4.4 Procedure

For this experiment, participants had to come with a competitor of their choosing. Both were informed of the objectives and the procedures of the session. On arrival, they were briefed on the tasks involved in the session and invited to confirm their understanding and participation by signing an informed consent form (Appendix II). Participants to this experiment were not paid but were given memorabilia items and learning material on the topic of the science of learning.

All tasks were performed in a dedicated computer laboratory with both participants in the same room as the experimenter. The first task was the pretest which was taken at the same time on different computers with the same characteristics. Participants were facing back to back so they could not see each other's screens. In any case, questions were randomised differently for each participant. The testing lasted three minutes. Once the pretest was finished, participants were explained the game instructions using visual aids (Appendix IV) and asked to choose a colour to identify which player they were. Participants were also given practice time (using a different corpus) with five trials to practice with the controls of the game. They were offered extra practice if needed, which used the same test corpus. Participants experienced 100 trials during game play and they were warned about the repetitive nature of the game in order to keep them on task. They were also instructed on the competitive nature of the game and that they were allowed to speak out and manifest their emotions while playing the game but that they were competing for the scores and that it was not a collaborative game. This point was particularly stressed after one pair of participants adopted this technique during the piloting phase. A board with previous pseudonyms and scores was visible to incentivise competition and active participation.

Once the game play task had finished, they immediately returned to their screens where the posttest was ready to be answered. They completed the assessment task without talking to one another. Once all tasks were finished, participants were thanked and asked whether they had any further questions. Participation finished with a further contact through email (a few weeks later) to send the results in a score chart. The session finished with the possibility for participants to ask questions. They were briefed on the project.

Results recorded in the computer were extracted daily and transferred to a working spreadsheet stored in the university server. Similarly, consent forms were kept for the duration of the study in a locked drawer in the laboratory. These were shredded once the study was finished.

6.4.5 Results

6.4.5.1 Hypotheses H_1 and H_2

Results form the pre and posttest were treated as in the previous experiments. For accuracy and response time, a percentage of the correct responses was obtained and then analysed using a test of difference. Table 6.10 shows a summary of the descriptive statistics for pre and posttest values in each condition. A Kolmogorov-Smirnov test indicated the normal distributions of the mean difference for accuracy, $D(51) = .082$, $p = .200$, and for response time, $D(51) = .110$, $p = .173$ so parametric tests were used.

Table 6.10
Summary of Descriptive Statistics for Experiment 5

	Motion			Static		
	Pretest	Posttest	Difference	Pretest	Posttest	Difference
Accuracy						
N	51	51	51	51	51	51
Mean	31.95	46.80	14.86	30.87	41.58	10.71
Std. Deviation	15.91	16.94	19.37	18.95	15.87	20.60
Minimum	0	10	-27.5	0	11.11	-47.12
Maximum	60	100	66.67	75	75	53.33
Response time						
N	51	51	51	51	51	51
Mean	48.94	44.25	-4.69	49.01	46.67	-2.34
Std. Deviation	10.28	7.36	13.15	11.86	8.54	14.60
Minimum	26.96	25.08	-49.12	22.81	25.15	-30.97
Maximum	77.85	56.86	23.09	73.49	68.23	29.92

Accuracy – H_1

Figure 6.13 depicts the distributions of the two groups in their values for the difference between pre and posttest for accuracy in each condition. The boxes show similar central distributions and very little difference between conditions. The motion condition presents a higher mean difference (M = 14.86, SD = 19.37) than the static condition (M = 10.71, SD = 20.6). This difference was not statistically significant as shown by a paired-samples t-test, $t(50) = 1.40$, $p = .169$, $d = 0.20$, 95% CI [-1.82, 10.1]. Therefore, the hypothesis H_1 cannot be supported. Tracking moving objects with semantic information and acting over them does not influence their better recall when compared with static objects.

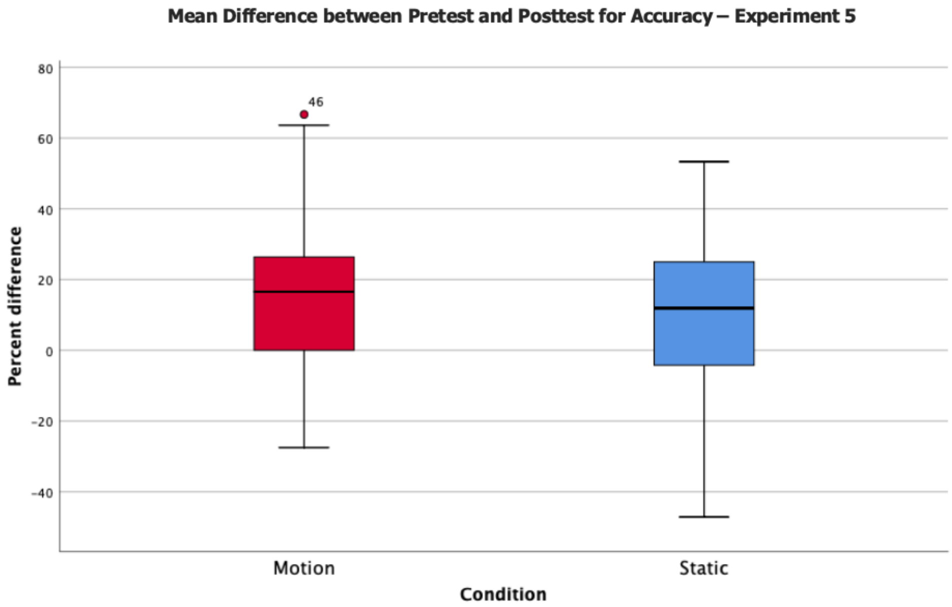


Figure 6.13. Mean difference in accuracy in Experiment 5. A percentage of the scores was calculated per participant and a mean difference between pre and posttest was obtained per condition.

Response time – H_2

Figure 6.14 shows the mean difference in RT between conditions. Whereas the medians are similar between conditions, the distribution shows that the motion condition tends to have lower mean RTs than the static condition. The mean difference between conditions showed that numbers learned in the motion condition were recognised faster (M = -4.69; SD = 13.2) than those learned under the static condition (M = -2.34; SD = 14.6). This 2.35% difference is, however, not statistically significant as shown by a paired-samples t-test, $t(50) = -.87$, $p = .386$, $d = 0.12$, 95% CI [-7.74, 3.04]. Therefore, hypothesis H_2 that prime numbers are recognised faster when they are learned under a motion game cannot be supported. The tracking of objects in motion did not have an effect on declarative learning as measured by faster response times.

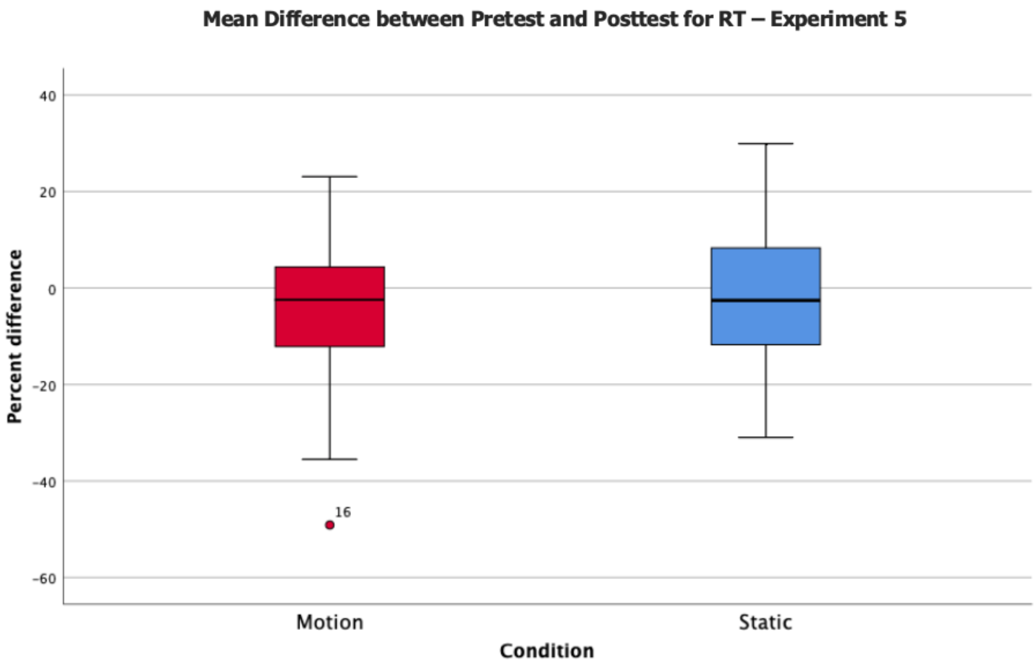


Figure 6.14. Mean difference between pre and posttest for RT in Experiment 5. Response time values correspond to a percentage of the RT per participant per condition.

6.4.5.2 Additional analyses – Game play and corpora analysis

Game-like task 2 in Experiment 5 - Accuracy

Game play in Experiment 5 had an average duration of 16.20 minutes (*SD* = 2.83) to complete a total of 100 trials divided equally for each of the conditions (Static: *N* = 50; Motion: *N* = 50).

Table 6.11 contains a summary of the descriptive statistics of game play.

Table 6.11
Summary of Descriptive Statistics for Game Play – Experiment 5

	Motion		Static	
	Accuracy (%)	RT	Accuracy (%)	RT
N	50	50	50	50
Mean	36.74	5.82	25.15	3.40
Std. Deviation	11.64	1.73	8.31	1.31
Minimum	8.00	1.95	8.00	1.78
Maximum	62.50	12.20	41.67	10.70

Figure 6.15 shows the relationship between trial number and the percentage of correct responses per condition. During game play, players showed a higher level of performance in the motion trials with a mean accuracy of 36.74% (*SD* = 11.64) compared to the static trials whose mean accuracy corresponded to 25.15% (*SD* = 8.31). This difference between the two conditions was statistically significant as shown by a paired-samples *t*-test, *t*(49) = 5.79, *p* < .001, *d* = 0.82, 95%CI [7.56, 15.61].

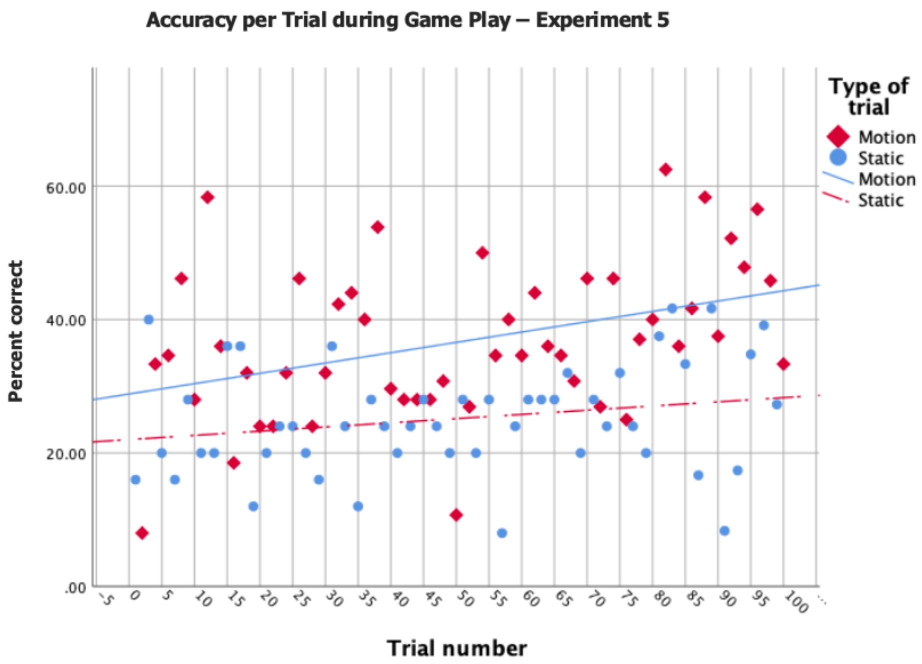


Figure 6.15. Accuracy per type of trial during game play in Experiment 5. A percentage of correct responses was calculated per trial. This is a two-player mode task with alternate trials beginning with the static condition by default.

Corpora analysis

Table 6.12 shows the detail for accuracy performance of the prime numbers used in this experiment. The highest rate of recognition did not reach 50% and the lowest is 20%. Primes appeared on average 262.2 times (*SD* = 22.45) and the average performance was 30.64% (*SD* = 7.77). Half of the numbers are over the average performance. In this analysis, no clear relationship can be observed between being a smaller prime and the rate of recognition as with the previous two corpora. It was previously suggested that more exposure to the task through extended play might increase recognition of primes which happened in Experiment 2 with increased game play time. This rate of response is lower than the one in Experiment 4 and it can be attributed to the fact that this game was played in a competitive way, so more errors as a result of trying to secure a response in time may have led to a detriment in accuracy.

Table 6.12
Corpora Performance During Game play – Experiment 5

	131	*149*	*181*	*193*	*379*	*127*	*163*	*179*	*191*	*373*
Number of times appeared	239	263	294	279	240	286	260	234	243	284
Number of CH	106	53	104	89	62	73	61	59	88	109
Performance (%)	44.35	20.15	35.37	31.90	25.83	25.52	23.46	25.21	36.21	38.38

6.4.6 Discussion of Experiment 5

Experiment 5 used Game-like task 2 modified for two players in a competitive mode. General results showed that although the means followed the direction of the hypotheses, there was no difference between the conditions to support the hypotheses H_1 and H_2 about the effect of tracking objects in motion on declarative memory formation. While, the descriptive statistics showed that game play had a higher percentage of prime numbers correctly identified in the motion trials, this gain was not transferred to the posttest.

The lack of transfer of learning observed in the pretest-posttest difference when higher accuracy was observed in the motion task game play phase raises a question about the sensitivity of the assessment task to pick up this difference. The presentation of the posttest is in line with the proportion of target and distractors, so it is not too distant from the original learning task. However, the assessment task and the static condition have a closer resemblance with regards to the mechanics for responding, as the numbers are also presented in static form in the assessment task.

The change of play mode to 2-players may be the explanation for this increase in accuracy in the motion trials, as this may have influenced the motivation of the players for the competition and consequently increased their engagement on the task and their willingness to succeed over the competitor. Vandercruysse et al (2013) investigated the effects of adding the element of competition to a language learning serious game and investigated its links to students' motivations, perceptions and learning outcomes. Their study showed no relationship between competition and students' learning gains and it only partly affected students' motivation. Conversely, Cagiltay et al. (2015) suggested that competition enhances learning and motivation because when motivation increased as a consequence of a competitive environment, so did the accuracy of scores in the game and these higher accuracy tended to increase posttest scores. However, Experiment 5 could not demonstrate this transfer of accuracy shown during game play to the posttest.

Anecdotal observations of the players during the session provided an indication of the level of competitiveness between players. Their dialogues and interjections showed a level of excitement and engagement on the task. They also seemed to develop strategies to deceive the opponent by making them believe the number they were after was a prime when it was really a distractor. Playing in competitive pairs made them more willing to defeat the opponent and win the game. Some players also acknowledged that the motion version of the game represented a greater challenge, but it was preferred because they felt it was more like a game. This engagement may have been demonstrated by the higher percentage of correct hits as trials progressed in the motion version of the game. However, this difference between conditions could not be demonstrated in the assessment task. This evidence might be in part related to Yu's (2003) suggestion that the most effective type of competition is when players do not know who they are competing with. In their study, a scenario in which players sat next to one another competing on the same learning game, i.e. face-to-face competition, was less effective in terms of promoting a learning environment than having competition at a decreased proximity or in an anonymous way. The students' perceptions about face-to-face interactions led to more losses in the game than when they had no possibilities of communicating with the opponent. A caveat to the study is that it focused on measuring the students' perception of the most favourable condition for learning, not the actual learning after playing. Also, their perceived processing was conducted in a real classroom context with primary school children who were randomly assigned to a dyad. Nevertheless, the study shows there is a naturally occurring engagement in a face-to-face competitive game similar to the one observed in Experiment 5. The usefulness of this engagement depends on the different scenarios and objectives.

Issues of power associated with the small sample size need to be considered as a possible reason for not being able to detect the desired effect of motion tracking on declarative memory.

The post-hoc analysis shows that the experimental design is underpowered and increasing its sensitivity might lead to larger effect sizes and avoid Type II Error (Appendix VIII).

This last experiment raises again the epistemological issue alluded to in the discussion of Experiment 4 concerning the problem of investigating learning of educational value with real-life characteristics in laboratory settings. A fair amount of balance has been given to the design of the task in terms of the elements to be included so that it can ressemble a real game while maintaining the ecological validity that would make findings appropriate for an educational context. This seems, however, a more complex task and cannot be only associated with the task but also to the methods used to collect data that can represent the full learning experience. Educational learning is a process involving biological structures that are differentiated, and in their interaction with the environment and the social world they change but not permanently, as the process continues during every moment of life.

6.5 Summary of the chapter

This chapter has covered the three experiments conducted in the Experimental Phase 2. Using a modified gaming task with more game-like features, the three experiments aimed at testing the hypotheses by modifying aspects of both the gaming and the assessment tasks to increase the sentitivity to detect the effect of motion tracking on declarative memory formation.

All experiments showed that the gaming task had an effect on learning as per comparison of the difference between pre and posttest, irrespective of the condition. There were no signs of ceiling or floor effects which may have interferred with the sensitivity of the design to detect a difference between the two conditions. Also, anecdotal data indicated that despite the simple mechanics of the game (compared to commercial games), participants still enjoyed playing it for being challenging and entertaining.

Nevertheless, no difference was observed in the recall of information learned through acting on moving or static objects, as measured by pre/posttest difference in accuracy and response times. Only Experiment 5, however, showed that during game play accuracy higher for information learned through the tracking of moving objects. Interestingly, this experiment added the element of social competition – embedded in a two-player mode. This was perceived as more engaging among the players and this may have acted favourably in conjuction with the motion tracking feature of the game and provided a more accurate recall while playing.

Experiments conducted in Phase 2 also led to the reflection of the epistemological issues of investigating learning using understandings of cognitive neuroscience and psychology and at the same time trying to provide ecological validity to a task in order to make it more authentic.

However, this lack of evidence for the benefits of motion tracking in declarative memory formation can be related to the underpowered design which did not enable to detecting an effect. It is important to mention that these issues of power were acknowledged and were mediated by the decision to continue advancing the experiments with the game-like tasks.

Chapter 7 General discussion and conclusions

This final chapter provides a discussion of the key points derived from the five experiments conducted to address the research question of the potential link between motion tracking and declarative memory. A summary of the research project and its findings introduces the discussion of their connection to previous literature and the implications for the theoretical underpinnings initially used to support this potential link, for research in the field and educational practice. The limitations to the present research as well as the future directions are also considered to explore the potential issues that may have led to the current findings in the light of epistemological questions around the field of educational neuroscience.

7.1 Summary of the project

The literature reviewed has shown that video games, especially the action genre, are associated with higher levels of engagement and attention in their players. This effect has been seen as potentially beneficial for educational purposes. However, evidence around video games for learning has been rather mixed mainly as a result of the lack of unified ways to research this field. This has led to a lack of clarity regarding what elements of video games contribute to learning through game play, which is the main topic of this research. In Chapters 2 and 3, literature was reviewed leading to the suggestion that the enhanced engagement and motivation triggered by video game play may eventually lead to learning due to the intimate relationship between attention and working memory generated while on the task. The successful interaction between these two sets of cognitive processes is a precondition to declarative memory formation, which is one of the most relevant forms of learning that takes place in educational contexts. However, the relationship between video games and declarative memory formation via video game play is less understood, and a desire to illuminate this relationship motivated this research.

Based on insights from visual cognition and cognitive neuroscience, this thesis explored whether attentively tracking objects in motion containing semantic information and acting upon them had an influence on declarative memory formation for that information in the context of an educational video game-like task. This declarative learning was measured by the accuracy and speed of recall of the learning content, comparing conditions in which information of semantic nature was presented in objects in motion that needed tracking compared with the same objects in a stationary mode. For such purpose, two computer game-like tasks were designed and coded for this research which considered the underlying processes of learning from a cognitive neuroscience and psychology perspectives as well as drawing on an educational understanding of learning while maintaining a certain level of ecological validity that would enable a potential use of games in educational contexts. The game-like tasks performed the role of a laboratory gamified task containing some of the main features of regular computer games. To explore the research question and the derived hypotheses, five experiments were conducted in which aspects associated with video game-based learning, such as time of exposure, number of items on screen, feedback and play mode were manipulated in order to test the hypotheses using a laboratory task that was closer to a more authentic video game play experience.

7.2 Summary of the findings

Two hypotheses were tested through five experiments in this research project. Hypotheses H_1 and H_2 tested the learning of prime numbers in terms of accuracy and speed of recognition respectively, calculated by the difference between pre and posttest mean scores and response times in each of the conditions (motion and static).

None of the experiments found that accuracy of responses (H_1) was increased as a result of playing a game-like task with the feature of motion compared to a static version, suggesting no evidence for detecting an effect of this feature on declarative memory formation. Although no studies have been found to investigate the effects of the specific feature of motion in learning through video games, this finding adds to the list of mixed evidence regarding the acquisition of knowledge or content through game-based learning (Connolly et al., 2012). The learning of content or knowledge is essential in educational settings and, therefore, a central aim for educational video games. Nevertheless, the different approaches used in game and research designs make comparisons among studies even harder. In the present study, no learning could be demonstrated by adding the feature of motion to the gaming task, suggesting that tracking motion might not be enough to promote declarative learning in this case.

Hypothesis H_2 that included the variable of speed of recognition as a proxy of learning was supported only in Experiment 2, which involved extended game play. This finding suggests that over time the feature of objects in motion had an effect on the speed of recognition of prime numbers, implying a higher level of automaticity in the processing. This evidence, though, was not found in the other experiments in which the duration of the game play was variable but held over one session only and not over five as in Experiment 2.

The findings from this research indicate a divergence from the hypothesis that enhanced attentional resources as a consequence of motion tracking would affect declarative memory.

Studies using the multiple object tracking and multiple identity tracking tasks have demonstrated that when attention is manipulated in the experiments, tracking performance is interfered with, revealing its deployment in these tasks (Scholl, 2009). However, in the present research which explored the application of this notion to the context of an educational video game, tracking objects in motion containing semantic information was not enough of a condition for enhancing the recall of such information in an assessment task, suggesting no effect on declarative memory formation. This evidence contrasts with the notion that visual tracking recruits more cognitive resources and as a consequence enhances tracking performance. Therefore, possible explanations for understanding this departure from the original hypothesis will be explored in the following sections of this discussion, which will focus around the theory used to support the potential link between motion tracking and declarative memory, and issues with the experimental design used for the research.

7.3 The link between tracking objects in motion and declarative memory

Based on insights from visual cognition and in particular using the attentive tracking paradigm as a basis (Makovski & Jiang, 2009a; Oksama & Hyönä, 2008; Pinto et al., 2012; Pylyshyn & Storm, 1988), it was hypothesised that there would be a potential relationship between visual motion tracking and declarative memory formation via the interaction of enhanced attentional deployment and working memory to maintain the binding (location-identity) of the objects being tracked. Although the present research did not used an MOT or MIT task per se, it used its principles to create a gaming task intended to engage attentional resources via moving objects that needed to be tracked for their location but mainly for their semantic properties, i.e. follow the trajectory of the different objects on screen to distinguish the prime number from the composite, and 'capture' it as part of the game play. The tracking and acting over such objects supposed the deployment of greater cognitive resources in the players and a higher potential for encoding the semantic information being presented in long-term storage. However, results from the experiments do not provide evidence for the hypothesis the feature of motion in the game had no effect on learning (measured by accuracy levels) compared to a game in which the objects remain stationary. Hence, this divergence from the hypothesised argument might be related to a possible misconstrued link between attentive tracking and declarative memory that might not occur in this context or to extra processing required for the formation of declarative memory that was not engaged as a result of motion tracking.

To review the potential link between motion tracking of object and declarative memory for their meaning, the first element to be considered is whether attention is triggered by motion tracking. Although initially, the original authors of the MOT task (Pylyshyn & Storm, 1988) considered tracking to be a preattentive mechanism, the involvement of attention for inhibiting distractors and for accessing information about the targets while tracking has later been acknowledged as part of the process (Scholl, 2009). Studies using multiple object tracking task and its variants (MOT and MIT) have demonstrated that tracking needs the deployment of attentional resources in order to perform well in the tracking task. In cases where the moving objects entail semantic information, i.e. a meaning that can lead to a categorisation such as prime/composite numbers, different theoretical approaches and models for multiple object tracking (Oksama & Hyönä, 2004, 2008) have given attention and working memory a role in the process of attentive tracking of objects with such properties (Scholl, 2009). However, there are no studies that attempt to establish a direct link between motion tracking and declarative memory formation. In fact, the involvement of attention and working memory are assumed as cognitive resources necessary for a successful tracking performance and have been widely studied (Allen et al., 2006; Endress et al., 2017; Harris et al., 2020; Makovski & Jiang, 2009b).

As explained by Oberauer (2019), when attention is seen as a process for selecting relevant information, which is how this research has understood the concept of attention, its relationship with working memory depends on the form of attention being displayed. Rather than attentional shifts of attention most predominantly seen in spatial cueing studies, attentive tracking requires sustained attention by definition that becomes divided because of the multiple objects being tracked, e.g. in an MOT task (Scholl, 2009). This is a comparable situation with an action video game, and in fact, the situation was recreated, particularly in Game-like task 2 in which there were four objects to be tracked. Three experiments (1, 2 and 5) showed that as the motion gaming task progressed, the number of correct responses increased, suggesting that the game-like task had a learning effect on players that could be attributed to the effect of tracking the moving objects with the corresponding information on the greater deployment of attention and working memory. However, this effect could not be detected in the other experiments (3 and 4), showing no difference between the different trials presented in the game-like task (motion and static). It is important to say that this effect was not exclusive to one game-like task, as it showed in both games used for this research. In the case of Game-like task 1, the adaptive feature embedded in the task enabled the calculation of the number of correct hits and also the number of missed hits as a result of the challenge imposed by the gaming task with the aim of preserving player's engagement. This enabled a combined measured of identification of prime numbers during the task, and it allowed to see this in spite of the difference in difficulty between the gamin taks. The interesting fact is that in the case of Game-like task 2, the learning effect during game play was evident in the motion trials when the gaming task was played in a 2-player mode, while when it was played individually, no difference was observed. Game-like task 2 did not have an adaptive feature like Game-like task 1, but it did have an algorithm to ensure equal time on screen for both types of trial, in order to provide the same amount of exposure to the numbers despite the different nature of the trials. Therefore, it can be implied that other elements around the situation of game play, e.g. the adaptive challenge to match performance or playing with a competitor, may have influenced the engagement with the game-like tasks and thus a better recall of the numbers learned in the motion trials.

Nevertheless, the lack of results indicates that there might be other elements required to complete the link between tracking and declarative memory. In fact, there are likely too many additional elements required for declarative memory formation, e.g. rehearsal of the information, emotional content associated with it, and the actual processing of semantic information. The processes of encoding and retrieval are steps for memory consolidation as they refine the representation of the information (Squire, 1994, 2004). For example, in line with the notion of testing knowledge, recurrent retrieval of semantic information contributes to its higher consolidation as it enables more representations of the item stored in memory (Karlsson Wirebring et al., 2015). In the present study, the possibility of retrieval is provided through game play as the sequences of numbers are repeated randomly and create a place for retrieval before the actual assessment task which is another possibility to do this. Another element that influences declarative memory formation is related to the emotional context of the items learned, as shown in an experiment with words, in which those that contained an emotional valance were better remembered than those that were neutral, but those that were neutral were better remembered when they were presented in an emotional context (Brierley et al., 2007). The present study used auditory and visual reinforcements of feedback on the experiments of Phase 2 to provide an association with the positive and negative feedback during the gaming task in order to reinforce the response given and support its encoding. Finally, the processing of declarative memory involves stages of encoding and retrieval that are, in turn, not single processes and need further steps. For example, encoding also involves the actions of perceiving and attending to the selected targets within the environment (Davachi & Dobbins, 2008). Therefore, the lack of results observed in the posttests could also be linked to issues with the encoding or with the retrieval of correctly encoded information. The design of the present study does not allow to confirm where in the processing the issue may have occurred.

Among the possible proposed explanations for a lack of effect on declarative memory, the study by Liu and colleagues (2012) suggested that the processing of identities in a tracking task required more cognitive resources, beyond attention, when the complexity of the targets was higher. In their study, they manipulated the size of numbers to be tracked to find that larger numbers of four digits were harder to identify because their vocalisation was longer and this influenced negatively the working memory span, which retained these numbers for a shorter time than when they were less complex, i.e. shorter. This suggests that identifying semantic properties during tracking requires more cognitive resources as cognitive load increases with object complexity. The corpora used in the experiments were three-digit numbers to maintain an adequate level of difficulty and avoid ceiling or floor effects in the assessment tasks. Double-digit numbers may have been easily remembered. However, in a learning gaming task, the complexity of the corpus will always be an issue as learning needs to be incremental in complexity, and there are some contents that in real-world learning cannot be manipulated to work better, e.g. vocabulary. In this case, the manipulation of other factors may act better, such as time of exposure or number of repetitions, type of feedback provided. Additionally, no floor effects were observed in the gaming tasks as a result of the complexity of the numbers. All posttests indicated gains in learning after playing the tasks irrespective of the condition, and learning was also demonstrated during game play, with better scores in motion game-like task in experiments 1, 2 and 5. This suggests that complexity due to the length of the numbers was not an issue in the study and an increase in cognitive load that would have hindered learning cannot be assumed.

Another way to review the assumption between tracking and declarative memory as proposed in the present research is to explore other processing necessary for declarative memory formation that may have not been initiated by the simple action of tracking motion. One assumption is that during game play, players may have not categorised the semantic information (prime/composite numbers) being tracked and the processing might have just remained at the feature level (numbers). Wei and colleagues (2018) established that the processing of semantic and feature categories involve different processing loads. The processing of semantic information is a goal-directed task that operates at a higher level and requires more resources, not only attention and working memory. It also needs a categorisation strategy that allows the transition of identities within the objects from a perceptual to a conceptual level, i.e. the formation of concepts and their categorical organisation. The authors suggested that this stage of the processing is the one that influences the encoding of the identity in the route of declarative memory formation. In the present research, the incorporation of such volitional strategy by the players can be hypothetically associated to their level of performance during the gaming task. This was partially observed in the analysis of game play, for example in Experiment 5, which showed that players had a better performance in the motion trials as compared to the static ones when playing with multiple objects on screen and in a scenario of social competition; or in Experiments 1 and 2 with only one object being tracked and an adaptive feature for fostering engagement in challenging trials. This gain, however, was not translated into higher scores in the assessment task (posttest), assuming a lack of retrieval of these memories and suggesting the processing of numbers may have remained at a perceptual level without accessing a deeper level of representation, at a concept level (Sloutsky, 2010), and therefore affecting the encoding of information.

Studies have shown that performance in category learning can be influenced by individual differences in visual and attentional processing (Schenk et al., 2020; West et al., 2015). Visual perception influences category learning which, in turn, needs the support of selective attention (Sloutsky, 2010). Action video game players tend to have an advantage in category learning (Schenk et al., 2020) which may be due to their capacity to direct attention more efficiently and a better perceptual system compared to those who are not avid players (West et al., 2015). The experiments in the present research did not follow a cross-sectional design as many of the studies in video game play, i.e. the comparison of players v/s non-players (Bavelier & Green, 2019). Therefore, the influence of individual differences on the results obtained could only be speculated in relation to category learning capacity, but it could be considered in further designs as the precise influence of playing action video games on category learning is still unknown (Schenk et al., 2020).

In sum, while the present research shows no evidence for supporting the notion that the feature of motion tracking embedded in a learning video game-like task can enhance declarative memory directly, some evidence could be obtained that attentional processes may have been positively impacted by motion tracking. Partial evidence (Experiments 1, 2 and 5) has shown that the game-like tasks involving the tracking of objects in motion are able to produce learning during game play and this may be attributed to the engagement of attentional resources that – in interaction with working memory – act as a gateway for this learning. This exclusive association of cognitive resources, however, does not seem to be enough to enhance declarative memory for semantic information contained in the tracked objects. The need for a deeper processing that enables the categorisation of the stimuli seems to be a missing link in this relationship between attentive tracking and declarative memory. Individual differences seem to have an effect on this level of processing, as avid action video game players seem to be better enabled for category learning which leads to better encoding. This suggests that higher exposure to game play may lead to this advantage, although it is not known which is the specific influence of playing action video games on category learning. Experiment 2 was the only experiment that showed gains from the motion game-like task in the posttest in the form of shorter response times, suggesting an increased level of automaticity. Interestingly, this experiment was conducted over a period of five days of practice with the gaming task and saw the evolution of the effects of motion tracking over time in terms of response time but with no difference for accuracy levels for which there was not sufficient encoding (MacLeod & Nelson, 1984). Therefore, although participants did not become avid players with the brief training experienced in Experiment 2, the time spent in playing with the motion game-like task may have led to the initial steps into the category learning process.

On another note, it may well be that the enhanced attention produced by the tracking objects in motion within a video game-like task cannot enhance the memory for the semantic properties of the objects because of broader and external processes that include the social and cultural aspects of video game play for learning. A study by Devonshire et al. (2014) demonstrated that a risk-based learning game, which was perceived as more engaging by students (compared to a non-risk version and a control), had more learning gains in a neuroscience multiple-choice test as a result of the socialisation of the terms learned among students during break time. This suggests that the feature of risk embedded in the game had an indirect effect on memory recall and played an interacting role in learning. Therefore, it is possible that the feature of motion embedded in gaming tasks has a modulating role in the processing of information rather than an independent direct influence. This process of socialisation of learning such as the ones that take place in educational contexts are difficult to detect in a laboratory experiment whose main concern is the exclusion of extraneous variables from the game. Certainly, future research will need to incorporate instances where the socialisation of learning becomes a variable to consider in the process of game-based learning. The need to consider the social world in the process of cognitive learning leads to question of the reducibility of a cognitive phenomenon in order to be studied from an educational neuroscience perspective, which will be addressed in the section related to the epistemological limitations of the present study.

Therefore, the link between motion tracking and declarative memory is not a misconstrued one, as game play shows that motion tracking does engage more attentional resources. It is, though, not enough for declarative memory formation because an additional and deeper level of processing may be required to encode and retrieve memories. Category learning as a step into declarative memory formation is more advantageous in avid action video game players, suggesting individual differences may be a strong influence in a better encoding of memories, but at the same time, it suggests the possibility of developing category learning via action video game play (Schenk et al., 2020). Additionally, the effects of video games for learning need to be seen beyond their performance and include the social aspects surrounding the culture of playing, as responses to the question of learning might be found there. It is possible that motion tracking acts as a modulator in learning via this social interaction.

The mixed results obtained in these experiments have been reviewed in the light of the theoretical association between motion tracking and declarative memory. They will be reviewed now in terms of methodological issues associated with the experimental design, based on the notion that the effect of motion tracking may have been theoretically present but the experimental design and tasks failed to detect it.

7.4 Methodological limitations

The second source of potential explanations for the results of the present research is the methodological domain, specifically related to the tasks used to detect the effect of motion tracking and declarative memory formation. In this research, two video game-like tasks were designed and coded to elicit the effect of motion tracking on declarative memory and an assessment task was designed to detect this effect in the form of a multiple-choice posttest.

Most research claiming the cognitive benefits of video game play have used off-the-shelf video games with the advantage of their being already-tested games from the perspective of their use and engagement with them. However, the fixed conditions of such games obstruct the flexibility needed for researching those particular game features that may contribute to the learning video games are attributed to produce. Entertainment video games are not focused on producing educational outcomes of curricular interest. Therefore, the measurable outcomes might not be of direct use in educational contexts, e.g. learning the tables of multiplication, but their cognitive outcomes are more in the line of cognitive benefits that would enhance the learning capacity (Bavelier et al., 2012; Bavelier & Green, 2019). The use of off-the-shelf video games for research also represents a difficulty in the control of the many variables associated with their features and game play dynamics, as experiments need to work with a limited set of variables in isolation. For example, many of these games contain complex game dynamics which offer players multiple possibilities of game play, generating unique game trajectories for each player. This is almost impossible to control for from an experimenter's perspective. A game-like task designed for the purposes of the study seems to be the optimal way to explore those elements within video games that promote learning and would also allow to obtain more accurate measures of learning, e.g. accuracy, response times and types of response, than if an off-the-shelf game is used. However, this solution is far from perfect, as even in research using games specifically designed for learning with most resemblance to entertainment video games, the issue of not knowing which features are most effective in promoting the intended learning remains a limitation (Jay et al., 2019). Therefore, the use of tailored software to investigate the particular feature of motion tracking was preferred in this study, instead of more accomplished graphics and complex game mechanics embedded in commercial and established video games. This design of a game-like task is bound by the research objectives which impose its limitations at the same time. A simplified design in order to isolate the main feature to be studied needed to leave out some of the main characteristics of video games and this may have affected its game dynamics, i.e. the relationship established between the game mechanics and the player (Hunicke et al., 2004). These design decisions may have become limitations to the study that are addressed as follows.

7.4.1 The game-like tasks

Creating a video game-like task that contains some (and not all) game-like features (to eliminate the confounding elements to the variable of motion tracking) posed a limitation in terms of the real gaming effect that could be achieved when compared to an off-the-shelf video game. This process entailed an explicit intention of highlighting certain qualities without the complete features of video games, which involved the risk of generating a perception of the game as bearing inferior quality, and thus becoming less engaging for the players and not fulfilling its purpose.

The design of the gaming task considered a balance among the key elements games, i.e. this was an experimental task oriented to produce learning while engaging players into a gaming situation. This was a difficult task to achieve and although it involved an iterative process which involved user testing in the design stages, it may well be that the balance among the elements may have acted to the detriment of how the gaming task was perceived and played by the participants. Game-like task 1 used a simpler interface with only one object on screen and no added features (e.g. sounds, visual effects) but with an adaptive algorithm to keep the player on task. The simplicity of the gaming task did not offer stages of development as most of the video games in the market. Therefore, an adaptive feature that considered the players' speed and type of response while playing made the gaming task more challenging and engaging for each player. Game-like task 2 dropped the adaptive algorithm used for the gaming task in Phase 1 as more elements were included on screen to increase the level of difficulty and more game-like feature were added to the task, e.g. sounds, more colours, visual effects. It is, however, possible that the absence of an adaptive feature may have made the gaming task more monotonous as the algorithm used for Game-like task 2 was changed to maintain a balance on the time of exposure to the numbers across conditions. As per the nature of the Game-like task 2, the alternate trials (motion/static) represented a discrepancy in times of exposure, i.e. responses in static trials take shorter time than in motion trials, as in the latter players need to wait for the numbers' trajectory to pass through a certain point in order to mark the answer. In this sense, some aspects such as the repetitive nature of the content within the tasks – due to the lack of increasing levels of difficulty – may have played a role on player's fatigue and affected the level of engagement with the task, leading to a decay in attentional processes and a further lack of encoding. The number of trials in a gaming task has an incidence in the playing time and this, in turn, may influence the depth of information processing, i.e. the encoding, retrieval, and consolidation of information. Nevertheless, irrespective of the number of trials, without an appropriate level of engagement and time on task, such value is meaningless.

The game-like tasks designed for the study emulated features of regular entertainment video games (Plass et al., 2015) but maintained a balance between the resemblance with a regular video game and the experimental purposes of the study. The gaming tasks were designed with a defined mechanics that contained the task and rules for players, which provided a supervised learning condition where feedback and reward guided the choices players made. The simple incentive system provided visual feedback and accumulated points but did not offer uncertain rewards to avoid a confounding variable for the engagement with the task. The gaming tasks also included elements of visual aesthetic design to emulate colourful palettes seen in regular video games. The use of narrative or a musical score were excluded from the design to reduce extraneous variables that could potentially confound the effect of motion. Finally, a learning content of factual nature was embedded in the gaming task, making it an educational game with entertainment features. With these considerations, the gaming task was deemed to be close enough to a real one to be perceived as a game more than as a laboratory task despite not having all the elements of regular games and eliciting the cognitive processes resulting from a tracking task. The degree of visual and mechanical sophistication of the game-like tasks was clearly lower compared to real action video games such as *Call of Duty* or the renowned *Fortnite*, whose graphical display and levels of complexity are much higher. However, there are classic examples of very simple games which are nevertheless fully engaging, such as *Tetris* or *Pong* in which the design was not centred on the graphics or levels of development of the game but in keeping the simplicity of an engaging task that required time-bound actions by the players which, if done correctly, earned points. In fact, evidence has shown that designs including more realistic visuals and graphics are not more effective for learning than designs that are more basic and use cartoon-like designs (Vogel et al., 2006; Wouters et al., 2013).

The limitations to the tasks may also connected to the possibilities of their design which were as well constrained by the use of a particular coding language with a limited set of features for designing games. The use of more sophisticated software was mediated ultimately by the coding skills of the researcher. The use of a professional coder may have resulted in potential disconnection with the design aims and programming features of the task and the researcher's lack of understanding of its operation, with the risks of losing information in case of malfunctioning of the task or other potential errors during the data collection process. Therefore, the game-like tasks in the present research are also a progressive representation of the researcher's understanding of game design for the specific purposes of this research. This may represent a limitation in the study in relation to the design of the data collection instruments.

As previously stated, it may well be that the enhanced attention produced by the tracking objects in motion cannot enhance the memory for the semantic properties of the objects because an additional set of processes are involved which include those reviewed above. The gaming task was conceived to provide a game-like situation that was easy to learn and command. In anecdotal accounts, players praised the gaming tasks, especially Game-like task 2 for its simple challenge that engaged them into playing. Hence, the ability of the task to induce the state of playing a game was fulfilled despite the constraints and limitations imposed by the design and technology used to build the task.

7.4.2 The assessment task

Another limitation concerns the assessment task and its possible lack of sensitivity to detect the differences between conditions in the gaming task. The design of the assessment task as a computer-based multiple-choice questionnaire (MCQ) presented four options for one correct response. The sets of numbers for each corpus, which were close in range, were presented in the same combination as during game play. All experiments showed a departure from the pretest results in the posttest (see these gains in Appendix VI) which suggests that the assessment task was sensitive enough to detect a change in learning produced after game play.

This way of assessment was preferred for two reasons. Firstly, the type of test (MCQ) as a way of testing resembles most educational testing of factual knowledge (Marsh et al., 2007) and in general respondents do well, even better than in short answer type of assessment (Funk & Dickson, 2011; Thiede, 1996; Voss, 1974). Secondly, the choice of a computer-based testing was made to preserve as much similarity with the learning environment as possible. This was important as research on the transfer of the learning gains to other contexts has not been conclusive, and this lack of transfer has been mainly attributed to the differences between the contexts of learning and application (Barnett, 2014). Nevertheless, Jay et al. (2019) conducted a training study in school children using computer games for learning and had successful transfer using a paper-based assessment task to measure arithmetic performance, which was a surprising finding. This could have been successful in educational contexts as pen and paper testing falls within the standard testing and students are more used to it.

Whereas a paper-based task was used in Experiment 3 to check whether there was a difference in recall using this format of assessment compared to the computer-based task, no difference was found between the two of them, and the computer test was preferred in the subsequent experiments as it provided information on accuracy but also on speed of recognition. A caveat to this is that the study by Jay et al. (2019) used the Westwood One-Minute Basic Number Facts Test (Westwood, 2013) which follows a short-answer assessment format, more suitable for assessing arithmetic problems. This differs from the MCQ format used in the current study which addresses the domain of memory recall of factual knowledge. However, the testing limitation could be associated with the resemblance of the MCQ with the static version of the game-like task, generating a more familiar environment for transfer. A priming effect might have affected the responses by finding them more similar to the source of learning (Nelson & Strachan,

2009) while the learning context for the motion version of the game-like task was more demanding and different.

Evidence from studies in the use of multiple-choice assessment have shown that MCQs might be a wrong indicator of what students can actually remember due to the possibility of guessing, and that the use of wrong alternatives presented might lead to their learning (Funk & Dickson, 2011; Marsh et al., 2007). In the present research, informal conversations with participants revealed that they sometimes felt confused about the numbers because they all looked similar, e.g. 269/267; 369/379; 129/127. Future testing which could include the use of a posttest that would request participants to elicit prime numbers instead of providing alternatives for responding might capture the effect of recall with fewer cognitive disruptions.

While the sensitivity of the assessment task can be a factor for the lack of evidence in this research, it is fair to say that it was sensitive enough to pick up the difference between pre and posttest in general. In all experiments, there was an increase in declarative knowledge which was shown by the increase in scores as well as the faster recognition in the posttests after a game play session. However, the sensitivity level cannot show any evidence of difference between conditions.

7.4.3 The sample

Sample size is a constant limitation for researchers. This research was caught up in the middle of the crisis of trust regarding the use of data and the new regulations of the GDPR which interfered with the way in which participants could be approached. This represented an additional hindrance to get participants to take part in a voluntary study. Furthermore, the experiments used a sample made up by university students of different ages and pathways but mostly from the area of education with little video gaming experience, and this may have biased the data in terms of the motivations for playing the gaming tasks and the potential level of engagement with the tasks presented. The conclusions from this study may, therefore, apply only to individuals within these demographics.

A post-hoc analysis (Appendix VIII) showed the experiment designs in general were underpowered. This is mainly due to the small sample sizes of the studies, suggesting higher number of individuals are required for the experiments to reach the alpha threshold. The effect sizes reported for the different studies are also small (± 0.2). A sensitivity test performed simulating a power of .95 indicated an increase in the minimal detectable effect to a medium to large effect, suggesting the number of participants in the present experiments was not sufficient to detect an effect that is not due to chance. In this research, the difficulty associated to participation recruitment was at stake as it was the progression of the studies. Therefore, the results obtained need to be considered with the issue of power observed across experimental designs and this should be considered for future research aiming to test the hypotheses of multiple object tracking and declarative memory formation.

Video game play is enjoyed across ages, especially children and youngsters at school age. The use of adults for testing a phenomenon that could be beneficial for educational contexts, and mainly for school-aged children, may be considered a potential limitation for the study. The use of a sample of adult participants in this research relates to a convenience sampling and the fact that it facilitated the access to multiple potential participants. Furthermore, the cognitive processes implied in this research via game play are more fully developed in adults than in children, such as working memory and attention deployment which follow a developmental pattern and increase with age until adulthood (Karatekin et al., 2007). In the case of working memory, research has found that age makes a difference, but this is not associated with children's lower capacity for encoding or allocating attention which is a capacity displayed by children (Cowan et al., 2011). Therefore, although there might be some developmental differences between age groups in terms of cognition, and the sample may not be fully representative of educational contexts that involve children, the two groups share the same underlying cognitive processes during learning through video game play. Additionally, this sample choice offers the possibility of acting as a piloting study before testing in a real-world context. This not only saves resources but it also allows to adjust for potential pitfalls and enhance the effectiveness of a future field study.

7.5 Epistemological limitations

One of the main challenges of this research has been ascribed to the goal of investigating the underlying processes and mechanisms involved in video game play and cognition while maintaining ecological validity. The aim of the five experiments was to isolate a particular feature, that of motion tracking, and study it in the absence of other contributory factors typically present in regular video games, such as the scheduling of uncertain rewards, a narrative supporting the goals of the game, or a fantasy world to be immersed in, among others. Therefore, the design of a game-like task that includes only certain gaming elements but keeps a degree of ecological validity may never reach the level of authenticity experienced with real video games played. This is not only because the game play experience was conducted in a laboratory setting but also because the extraneous factors cannot be present in the experimental game-like task.

The apparent contradiction of conducting a laboratory experiment to test a real-life activity, such as video game play, represents a limitation that cannot be escaped. Although the present games led to an observed engagement with the task and to a learning effect irrespective of the condition, the environment was still likely to have been perceived as a laboratory task and may have not contributed to the full experience of flow that takes place in authentic personal individual or collective spaces of game play. Learning in classrooms, for example, involve aspects of the social world that influence such learning, making it a process less likely to be controlled compared to when it occures in a laboratory setting. Therefore, the attempt to produce a laboratory task that could be classroom-relevant containing declarative knowledge is not only a hard endeavour but also a potential difficulty to find an effect, if it exists. The alternative to this, i.e. pure experimental tasks that avoid extraneous factors or educational-relevant stimuli could be used to establish the effects first and then transfer to more ecologically-valid contexts.

This leads to the question whether the attempt here to use experiments that are both systematic and controlled, and relevant to education is a philosophical contradiction. The question of the validity of laboratory experiments for detecting processes of both biological and social nature that contribute to the learning processes of the students emerges from the fact that each science has its own epistemologies and thus methods to investigate phenomena (Han et al., 2019). In the present research, the use of experiments was useful to exclude extraneous variables, but at the same time, including those variables may have enhanced our understanding of the phenomenon being studied. However, traditional divisions of epistemologies would consider this a mistake that would have played against the validity of the data. The challenge may be to propose new ways of exploring a phenomenon that includes different sorts of variables in semi-controlled environments. The use of mixed methodologies seems an appropriate starting point for investigating educational learning as a scientific matter. On the one hand, the use of quantitative methods enables the capture of the underlying cognitive processes in controlled environments, e.g. at a laboratory level, to expand knowledge; and on the other hand, qualitative methods contribute to the understanding of the environmental factors and personal experience associated with such cognitive processes in educational contexts to further the science of learning.

Models to understand how to do science in the field of educational neuroscience have pointed to the need of different types of experiments (Howard-Jones, 2010) and to the division of different levels of explanation, each with their own epistemologies and methodologies (Han et al., 2019) (see Figure 4.3). The acknowledgement of this segmentation in possible approaches to research in this field leads to the question of power concerning the balance in the input provided by each epistemology, namely is there the need of a ruling science from which the approach departs? Which science informs the other? Is it neuroscience to education or vice versa? The necessary answers to these questions are key to address the challenges that may emerge from the methodological decisions taken. As with every other research, there are no correct responses as every context might differ but a discussion around this from a philosophical perspective would contribute to the development of the ontology of educational neuroscience.

7.6 Implications and further research

The present study adds to the current research in terms of the approach used to study the effect of a particular feature – motion of objects – within action video games on declarative learning of educational value, based on attentive tracking theories and cue-directed actions that engage shifts in attentional direction. There is a vast amount of research on video games and their effects for learning, but few, to the best of my knowledge, that have attempted to: a) isolate a feature of video games to study it; b) design a game-like task that would serve the purpose in a); and c) study declarative memory formation via motion tracking. Other similar studies have either created a video game but not isolated any particular features, or associated different variables through the use of educational video games or entertainment video games. For example, Prena et al. (2018) also studied the effects of a specific feature of video games – reward – on declarative memory but by using off-the-shelf video games bearing the type of reward they were studying. Habgood and Ainsworth (2011) created a maths learning video game with many of the elements of commercial video games for making the experience more authentic to research intrinsic integration and learning. Jay et al. (2019) also created an educational video game for learning maths and used moving objects on screen together with many other features of video games that did not let them understand what elements of the game contributed to the gains in learning. Therefore, the present research contributes to the field of video game research as an experimental study that offers a perspective of value-added research (Mayer, 2015, 2019), by exploring a specific game element for its value-added possibilities from an instructional perspective.

This study is an original contribution in terms of the theoretical approach used to investigate the feature of motion tracking in video game-like tasks and learning. Theories of visual cognition, such as the MOT and MIT paradigms, support the idea that objects in motion recruit attentional resources and working memory, and the present study hypothesised that this could be a link that may influence learning of declarative nature. One of the main features of action video games is the fast-paced movements of elements on screen that need to be tracked in order to accomplish the game goals. Research has already highlighted the cognitive benefits to those who play this kind of games (Bediou et al., 2018) and that could be beneficial for learning to learn (Bavelier et al., 2012). This study also assumes an educational neuroscience perspective in which evidence from cognitive neuroscience and psychology is used to understand how through technology learning that is relevant to educational contexts can be produced. Although this is not a brain study itself, the neuroscience evidence used in this research has served the purpose to complement psychological explanations of declarative memory, attention and working memory, and expand the understandings of cognition. This evidence, added to the inclusion of educational understandings of learning are a contribution to the development of educational games initially for research purposes and eventually for game design for commercial endeavours.

Many of the issues revealed in this study could be addressed in further research by means of modifications to the research design via the incorporation of different methods or techniques into the study, as well as alterations or enhancements to the game design. Considering the possibility that motion tracking could have more of an indirect effect on learning – as a modulator in the socialisation of learning – a further study could be better designed if it incorporates measures of social discourse around the activity of game play. Similarly, an enhancement of the gaming environment within laboratory conditions could further encourage a gaming attitude among participants.

Game-like task designs are always perfectible as a result of the iterative process they go through during the design process. A design that incorporates more stages that extend the gaming task in both time and difficulty would enable participants to play for a longer time without losing the engagement and inciting a continuous game play. These modifications are more appropriate for an intervention approach which due to potential costs is more suitable for a major scale project.

The use of mixed methods to collect information on the learning process via video game play would be advisable in future studies. As previously shown, some of the anecdotal comments by players provide an extra source of information on their learning process. Self-reported questionnaires to be answered after their participation could be helpful in determining how players perceive their learning in the game-like task. This may help understand the relationship between a player's self-perception and their actual performance, with the possibility of establishing patterns (if any) of learning in relation to individual perceptions. Recording conversations among players would be another way to further explore their learning. As shown with the study by Devonshire et al. (2014), the use of a risk-based learning game had a modulating effect on learning as the element of risk did not make a direct difference in learning, but an indirect one by enabling further conversations and discussions among students on what was being learned. This, of course, occurred outside the controlled experienced of the game play. Thus, the importance of using methodologies to capture as many possible elements and circumstances involved in the learning process within educational contexts.

The use of different formats of technology could also be explored in future research. The gaming task could be designed to fit the use of portable devices that allow playing via touch system. This would allow players more freedom to play when it is wanted more than when it is commanded and may also shed light on play habits and how they relate to learning. The playing mode might necessarily interfere with the possibilities of controlling the variables. Here again, we face the issue of studying a natural phenomenon with a laboratory approach. Therefore, changes to research design to fit one or the other option will necessarily follow a degree of compromise. All of these additions to a more portable game could make good use of learning analytics to seamlessly provide information on multiple variables that could be potentially analysed and modelled to find the most accurate and tailored way to learn via video game play for each player. This use of more 'natural' ways of gaming could also contribute to maintain the authentic experience of game play and make results more valid and generalisable to real-life learning contexts. Following this idea of more natural measurements of performance, the use of wearable devices and quantified-self tracking tools (Przegalińska, 2015) could evolve in the future to have a role in researching learning through games in authentic contexts without the interference of a laboratory setting or cumbersome measuring technology.

Following recommendations for value-added type of research proposed by Mayer (2019), the field needs to expand its research with techniques for measuring and looking into the cognitive processes of video game play. The use of methods such as psychophysiology, eye tracking or cognitive neuroscience methods could be useful to see how the different features of games influence the learning process and complement the behavioural measures to further the understanding of how brain-mind-behaviour operate. Eye tracking studies have been used to observe the distribution of visual attention in studies using video games for learning (Chukoskie et al., 2018; Conati et al., 2013). The use of this technique follows the understanding that patterns in visual attention reflect mental attention patterns that, in turn, reflect cognitive strategies used by individuals (Antonenko, 2019). While eye tracking would have been seen like an obvious method to use in the present research for measuring the allocation of attention to the moving objects during game play, its use was discarded at this stage due to its cumbersome implementation that would have interfered with the natural way of playing a video game that was being pursued in the study. However, in future research and using a perhaps more seamless eye-tracking system, the use of a method to measure allocation of attention and correlate it with performance may be a valid indicator to understand whether (but also, how and when) the gaming task triggered attention to the moving targets and how these levels of attention allocation contribute to declarative memory formation.

Other methods that can be used to understand the phenomenon at brain level are said to be non-invasive from a health perspective, but they impose some degree of physical invasiveness when used in more authentic experimental settings that try to recreate real-world conditions. The use of electroencephalography (EEG) would be appropriate to understand *when* changes take place at a brain level thanks to its excellent temporal resolution. The measurement of high-frequency of alpha activity has shown to be correlated with the processing of semantic information (Klimesch et al., 2005, 2006), and the use of this measure could shed light on the articulation of the stimuli strength and time needed for the processing of semantic information. Additionally, this technique has been refined over the years, made it less invasive and in some cases portable, allowing data collection from multiple participants even in interaction (Dikker et al., 2017), which may be better used to illustrate how learning processes occur in real gaming situations.

The use of brain imaging with better spatial resolution than the EEG, such as functional magnetic resonance imaging (fMRI) and functional near infrared spectroscopy (fNIRS), serves the purpose of indicating where the cognitive changes occur in the brain. In terms of the present research, an MRI could provide information on the regions of interest (ROI) that activate or deactivate at the different stages of the gaming task, such as monitoring, tracking and receiving feedback after the responses, but also how the semantic information is processed through enhanced attention fostered by motion tracking. Brain research has already illustrated brain activity with action video game play and the regional differences between avid players and non-players (Bavelier et al., 2012). The anterior cingulate cortex (ACC) has been shown activation with video game play consistently across studies (Palaus et al., 2017) and is associated with the involvement of attentional control (selective, sustained and divided attention). Research using the multiple identity tracking paradigm has also identified the activation of the ACC but also of the fusiform and IFG pars triangularis involved in the representation of semantic information in the brain. The latter is also associated with the categorisation of semantic knowledge which seems to be the level of depth necessary for declarative memory formation (Wei et al., 2017). Finally, the medial temporal lobe (MTL) structures have been identified as the centre for declarative memory formation, with a special emphasis in the hippocampus. For this research, a brain study would need to look at how these ROIs interact during the process of selecting, sustaining and dividing attention while identifying and categorising semantic knowledge via video game play with an emphasis on the motion feature. This could also inform the effectiveness of the game-like task being used to elicit such cognitive processes. While the main requirement for fMRI use is to remain motionless while lying in the scanner bed, playing a game-like task through the use of clickers is possible, but it is far from being an authentic game play situation. Instead, fNIRS offers a technique that can be better used for looking into questions that associate brain localisation within the cognitive processes involved in the tracking of objects in motion during game play, as it can tolerate motion of the individuals while being used.

Finally, whichever the technique, research design or gaming task design is used for further research, a consideration to philosophical issues in the field of educational neuroscience needs to guide the decisions of prioritisation of aims. Finding a right balance between education and neuroscience objectives could be a hard task, but at least there needs to be an acknowledgement of this effort to bring validity to the study, especially for the educational world.

7.7 Conclusions

Research on video games has claimed its benefits for a myriad of cognitive skills that are potentially useful for learning via enhanced motivation and engagement of players. Alongside this line of research, the need for understanding the underlying processes of such potential by researching the effects of specific features of video games on cognitive processes has been emphasised.

Using insights from visual cognition and cognitive psychology and neuroscience, this research proposed a theoretical understanding for investigating the relationship between one of the primary features of action video games, the tracking of objects in motion, and declarative memory formation via the enhancement of attentional resources. This series of experiments sought to explore the link between tracking of objects in motion that contained semantic information and declarative memory for such information by means of video game play. However, due to issues of power related to sample size, results failed to provide evidence that visually tracking objects in motion enhanced declarative memory by itself. In some studies, motion tracking seemed to improve performance during game play which might suggest higher levels of attention, but this was not enough for the retrieval of information in a posttest.

The findings from this research provide no evidence to indicate that motion tracking on its own can provide a strong enough contribution to declarative memory formation of interest to educators. This discussion has reviewed the original idea of the association between visual tracking and memory enhancement, the potential experimental issues involving the sensitivity of the task, the power of the experimental design and the epistemological limitations imposed by the need for conducting laboratory experiments to understand real-world phenomena at the interface of educational neuroscience. The use of a novel game-like task, tailored for the experiments, has provided some insights on the potential pitfalls of the study and contributed an example of the steps to follow or to avoid in further research in this field. This series of experiments showed that object motion tracking embedded in a learning video game-like task may activate additional attentional resources while playing, but this does not necessarily imply that players will learn the information about the semantic content presented. In this case, attention is necessary but not sufficient for learning through video game play. The potential explanations for this result need further investigation. However, this should not be understood as an indication for not pursuing further research in video games for learning. On the contrary, a relevant question arising from this research is the need to continue investigating other features contained in video games that may influence cognitive processes of interest for the educational contexts.

References

Adcock, R. A., Thangavel, A., Whitfield-Gabrieli, S., Knutson, B., & Gabrieli, J. D. E. (2006). Reward-Motivated Learning: Mesolimbic Activation Precedes Memory Formation. *Neuron*, *50*(3), 507–517. https://doi.org/10.1016/j.neuron.2006.03.036

Agrillo, C., Miletto Petrazzini, M. E., & Bisazza, A. (2014). Numerical acuity of fish is improved in the presence of moving targets, but only in the subitizing range. *Animal Cognition*, *17*(2), 307–316. https://doi.org/10.1007/s10071-013-0663-6

Alessi, S. M., & Trollip, S. R. (2001). *Multimedia for learning: Methods and development*. Allyn & Bacon.

Allen, R., McGeorge, P., Pearson, D. G., & Milne, A. (2006). Multiple-Target Tracking: A Role for Working Memory? *Quarterly Journal of Experimental Psychology*, *59*(6), 1101–1116. https://doi.org/10.1080/02724980543000097

Allen, R., McGeorge, P., Pearson, D., & Milne, A. B. (2004). Attention and expertise in multiple target tracking. *Applied Cognitive Psychology*, *18*(3), 337–347. https://doi.org/10.1002/acp.975

Alnæs, D., Sneve, M. H., Richard, G., Skåtun, K. C., Kaufmann, T., Nordvik, J. E., Andreassen, O. A., Endestad, T., Laeng, B., & Westlye, L. T. (2015). Functional connectivity indicates differential roles for the intraparietal sulcus and the superior parietal lobule in multiple object tracking. *NeuroImage*, *123*, 129–137. https://doi.org/10.1016/j.neuroimage.2015.08.029

Alvarez, G. A., & Franconeri, S. L. (2007). How many objects can you track? Evidence for a resource-limited attentive tracking mechanism. *Journal of Vision*, *7*(13), 14.1-10. https://doi.org/10.1167/7.13.14

Alvesson, M., & Sköldberg, K. (2009). *Reflexive methodology: New vistas for qualitative research* (2nd ed). SAGE.

Amso, D., & Scerif, G. (2015). The attentive brain: Insights from developmental cognitive neuroscience. *Nature Reviews Neuroscience*, *16*(10), 606–619. https://doi.org/10.1038/nrn4025

Anchor, R. (1978). History and Play: Johan Huizinga and His Critics. *History and Theory*, *17*(1), 63. https://doi.org/10.2307/2504901

Ansari, D., Smedt, B. D., & Grabner, R. H. (2012). Neuroeducation – A Critical Overview of An Emerging Field. *Neuroethics*, *5*(2), 105–117. https://doi.org/10.1007/s12152-011-9119-3

Antonenko, P. D. (2019). Educational Neuroscience: Exploring Cognitive Processes that Underlie Learning. In T. D. Parsons, L. Lin, & D. Cockerham (Eds.), *Mind, Brain and Technology: Learning in the Age of Emerging Technologies* (pp. 27–46). Springer International Publishing. https://doi.org/10.1007/978-3-030-02631-8_3

Arnab, S., Brown, K., Clarke, S., Dunwell, I., Lim, T., Suttie, N., Louchart, S., Hendrix, M., & de Freitas, S. (2013). The development approach of a pedagogically-driven serious game to support Relationship and Sex Education (RSE) within a classroom setting. *Computers & Education*, *69*, 15–30. https://doi.org/10.1016/j.compedu.2013.06.013

Ashby, F. G., & Crossley, M. J. (2012). Automaticity and multiple memory systems. *Wiley Interdisciplinary Reviews: Cognitive Science*, *3*(3), 363–376. https://doi.org/10.1002/wcs.1172

Baayen, R. H., & Milin, P. (2010). Analyzing reaction times. *International Journal of Psychological Research*, *3*(2), 12–28. https://doi.org/10.21500/20112084.807

Baddeley, A. D., & Hitch, G. (1974). Working Memory. *Psychology of Learning and Motivation*, *8*, 47–89. https://doi.org/10.1016/S0079-7421(08)60452-1

Baddeley, A. D., & Logie, R. H. (1999). Working memory: The multiple-component model. In *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 28–61). Cambridge University Press. https://doi.org/10.1017/CBO9781139174909.005

Bahmani, Z., Clark, K., Merrikhi, Y., Mueller, A., Pettine, W., Isabel Vanegas, M., Moore, T., & Noudoost, B. (2019). Prefrontal Contributions to Attention and Working Memory. *Current Topics in Behavioral Neurosciences*. https://doi.org/10.1007/7854_2018_74

Bakhurst, D. (2008). Minds, Brains and Education. *Journal of Philosophy of Education*, *42*(3–4), 415–432. https://doi.org/10.1111/j.1467-9752.2008.00645.x

Barlow, H. B. (1989). Unsupervised Learning. *Neural Computation*, *1*(3), 295–311. https://doi.org/10.1162/neco.1989.1.3.295

Barnett, S. M. (2014). Virtual to Real Life—Assessing Transfer of Learning from Video Games. In F. Blumberg (Ed.), *Learning by playing: Video gaming in education* (pp. 15–28). Oxford University Press.

Barto, A. G. (1995). Reinforcement learning. In M. A. Arbib (Ed.), *The handbook of brain theory and neural networks* (pp. 804–809). MIT Press.

Bavelier, D., & Green, C. S. (2019). Enhancing Attentional Control: Lessons from Action Video Games. *Neuron*, *104*(1), 147–163. https://doi.org/10.1016/j.neuron.2019.09.031

Bavelier, D., Green, C. S., Han, D. H., Renshaw, P. F., Merzenich, M. M., & Gentile, D. A. (2011). Brains on video games. *Nature Reviews Neuroscience*, *12*(12), 763–768. https://doi.org/10.1038/nrn3135

Bavelier, D., Green, C. S., Pouget, A., & Schrater, P. (2012a). Brain Plasticity Through the Life Span: Learning to Learn and Action Video Games. *Annual Review of Neuroscience*, *35*(1), 391–416. https://doi.org/10.1146/annurev-neuro-060909-152832

Bavelier, D., Green, C. S., Pouget, A., & Schrater, P. (2012b). Brain Plasticity Through the Life Span: Learning to Learn and Action Video Games. *Annual Review of Neuroscience*, *35*(1), 391–416. https://doi.org/10.1146/annurev-neuro-060909

Beale, I. L., Kato, P. M., Marin-Bowling, V. M., Guthrie, N., & Cole, S. W. (2007). Improvement in Cancer-Related Knowledge Following Use of a Psychoeducational Video Game for Adolescents and Young Adults with Cancer. *Journal of Adolescent Health*, *41*(3), 263–270. https://doi.org/10.1016/j.jadohealth.2007.04.006

Beauchamp, C., & Beauchamp, M. H. (2013). Boundary as Bridge: An Analysis of the Educational Neuroscience Literature from a Boundary Perspective. *Educational Psychology Review*, *25*(1), 47–67. https://doi.org/10.1007/s10648-012-9207-x

Bediou, B., Adams, D. M., Mayer, R. E., Tipton, E., Green, C. S., & Bavelier, D. (2018). Meta-Analysis of Action Video Game Impact on Perceptual, Attentional, and Cognitive Skills. *Psychological Bulletin*, *144*(1), 77–110. https://doi.org/10.1037/bul0000130

Berridge, K. C., & Robinson, T. E. (1998). What is the role of dopamine in reward: Hedonic impact, reward learning, or incentive salience? *Brain Research Reviews*, *28*(3), 309–369. https://doi.org/10.1016/S0165-0173(98)00019-8

Bhaskar, R. (1979). *The possibility of naturalism: A philosophical critique of the contemporary human sciences*. The Harvester Press.

Bhaskar, R. (1989). *Reclaiming reality: A critical introduction to contemporary philosophy*. Verso.

Bisazza, A., Piffer, L., Serena, G., & Agrillo, C. (2010). Ontogeny of Numerical Abilities in Fish. *PLOS ONE*, *5*(11), e15516. https://doi.org/10.1371/journal.pone.0015516

Blacker, K. J., & Curby, K. M. (2013). Enhanced visual short-term memory in action video game players. *Attention, Perception, & Psychophysics*, *75*(6), 1128–1136. https://doi.org/10.3758/s13414-013-0487-0

Blacker, K. J., Curby, K. M., Klobusicky, E., & Chein, J. M. (2014). Effects of action video game training on visual working memory. *Journal of Experimental Psychology. Human Perception and Performance*, *40*(5), 1992–2004. https://doi.org/10.1037/a0037556

Blakemore, S.-J., & Frith, U. (2005). *The learning brain: Lessons for education*. Blackwell.

Blascovich, J., & Bailenson, J. (2011). *Infinite reality: Avatars, eternal life, new worlds, and the dawn of the virtual revolution* (1st ed). William Morrow.

Bliss, T. V. P., & Lømo, T. (1973). Long-lasting potentiation of synaptic transmission in the dentate area of the anaesthetized rabbit following stimulation of the perforant path. *The Journal of Physiology*, *232*(2), 331–356. https://doi.org/10.1113/jphysiol.1973.sp010273

Bonanni, R., Natoli, E., Cafazzo, S., & Valsecchi, P. (2011). Free-ranging dogs assess the quantity of opponents in intergroup conflicts. *Animal Cognition*, *14*(1), 103–115. https://doi.org/10.1007/s10071-010-0348-3

Boot, W. R., Kramer, A. F., Simons, D. J., Fabiani, M., & Gratton, G. (2008). The effects of video game playing on attention, memory, and executive control. *Acta Psychologica*, *129*(3), 387–398. https://doi.org/10.1016/j.actpsy.2008.09.005

Bowers, J. S. (2016). The practical and principled problems with educational neuroscience. *Psychological Review*, *123*(5), 600–612. https://doi.org/10.1037/rev0000025

Boyle, E. A., Hainey, T., Connolly, T. M., Gray, G., Earp, J., Ott, M., Lim, T., Ninaus, M., Ribeiro, C., & Pereira, J. (2016). An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games. *Computers & Education*, *94*, 178–192. https://doi.org/10.1016/j.compedu.2015.11.003

Brierley, B., Medford, N., Shaw, P., & David, A. S. (2007). Emotional memory for words: Separating content and context. *Cognition and Emotion*, *21*(3), 495–521. https://doi.org/10.1080/02699930600684963

Brockhoff, A., Papenmeier, F., Wolf, K., Pfeiffer, T., Jahn, G., & Huff, M. (2016). Viewpoint matters: Exploring the involvement of reference frames in multiple object tracking from a developmental perspective. *Cognitive Development*, *37*, 1–8. https://doi.org/10.1016/j.cogdev.2015.10.004

Brown, T. I., Ross, R. S., Tobyne, S. M., & Stern, C. E. (2012). Cooperative interactions between hippocampal and striatal systems support flexible navigation. *NeuroImage*, *60*(2), 1316–1330. https://doi.org/10.1016/j.neuroimage.2012.01.046

Bruer, J. T. (1997). Education and the Brain: A Bridge Too Far. *Educational Researcher*, *26*(8), 4–16. https://doi.org/10.3102/0013189X026008004

Burgers, C., Eden, A., van Engelenburg, M. D., & Buningh, S. (2015). How feedback boosts motivation and play in a brain-training game. *Computers in Human Behavior*, *48*, 94–103. https://doi.org/10.1016/j.chb.2015.01.038

Byrnes, J. P. (2001). *Minds, brains, and learning: Understanding the psychological and educational relevance of neuroscientific research*. Guilford Press.

Byrnes, J. P. (2009). *Cognitive development and learning in instructional contexts*. Pearson International.

Cagiltay, N. E., Ozcelik, E., & Ozcelik, N. S. (2015). The effect of competition on learning in games. *Computers & Education*, *87*, 35–41. https://doi.org/10.1016/j.compedu.2015.04.001

Caillois, R. (2001). *Man, play, and games* (M. Barash, Trans.). University of Illinois Press.

Cain, M. S., Landau, A. N., & Shimamura, A. P. (2012). Action video game experience reduces the cost of switching tasks. *Attention, Perception, & Psychophysics*, *74*(4), 641–647. https://doi.org/10.3758/s13414-012-0284-1

Cameron, B., & Dwyer, F. (2005). The Effect of Online Gaming, Cognition and Feedback Type in Facilitating Delayed Achievement of Different Learning Objectives. *Journal of Interactive Learning Research*, *16*(3), 243–258.

Cavanagh, P., & Alvarez, G. A. (2005). Tracking multiple targets with multifocal attention. *Trends in Cognitive Sciences*, *9*(7), 349–354. https://doi.org/10.1016/j.tics.2005.05.009

Chamoun, M., Huppé-Gourgues, F., Legault, I., Rosa-Neto, P., Dumbrava, D., Faubert, J., & Vaucher, E. (2017). Cholinergic Potentiation Improves Perceptual-Cognitive Training of Healthy Young Adults in Three Dimensional Multiple Object Tracking. *Frontiers in Human Neuroscience*, *11*. https://doi.org/10.3389/fnhum.2017.00128

Chen, G., Cheng, W., Chang, T.-W., Zheng, X., & Huang, R. (2014). A comparison of reading comprehension across paper, computer screens, and tablets: Does tablet familiarity matter? *Journal of Computers in Education*, *1*(2), 213–225. https://doi.org/10.1007/s40692-014-0012-z

Chesney, D. L., & Haladjian, H. H. (2011). Evidence for a shared mechanism used in multiple-object tracking and subitizing. *Attention, Perception & Psychophysics*, *73*(8), 2457–2480. https://doi.org/10.3758/s13414-011-0204-9

Chisholm, J. D., & Kingstone, A. (2012). Improved top-down control reduces oculomotor capture: The case of action video game players. *Attention, Perception & Psychophysics*, *74*(2), 257–262. https://doi.org/10.3758/s13414-011-0253-0

Chukoskie, L., Westerfield, M., & Townsend, J. (2018). A novel approach to training attention and gaze in ASD: A feasibility and efficacy pilot study. *Developmental Neurobiology*, *78*(5), 546–554. https://doi.org/10.1002/dneu.22563

Clark, J. (2015). Philosophy, Neuroscience and Education. *Educational Philosophy and Theory*, *47*(1), 36–46. https://doi.org/10.1080/00131857.2013.866532

Cohen, J. D., Perlstein, W. M., Braver, T. S., Nystrom, L. E., Noll, D. C., Jonides, J., & Smith, E. E. (1997). Temporal dynamics of brain activation during a working memory task. *Nature*, *386*(6625), 604–608. https://doi.org/10.1038/386604a0

Cohen, M. A., Pinto, Y., Howe, P. D. L., & Horowitz, T. S. (2011a). The what–where trade-off in multiple-identity tracking. *Attention, Perception, & Psychophysics*, *73*(5), 1422–1434. https://doi.org/10.3758/s13414-011-0089-7

Cohen, M. A., Pinto, Y., Howe, P. D. L., & Horowitz, T. S. (2011b). The what–where trade-off in multiple-identity tracking. *Attention, Perception, & Psychophysics*, *73*(5), 1422–1434. https://doi.org/10.3758/s13414-011-0089-7

Colzato, L. S., Van Leeuwen, P. J. A., Van Den Wildenberg, W., Hommel, B., Colzato, L. S., Leeuwen, P. J. A. van, Wildenberg, W. P. M. van den, & Hommel, B. (2010). DOOM'd to switch: Superior cognitive flexibility in players of first person shooter games. *Cognition*, *1*, 8. https://doi.org/10.3389/fpsyg.2010.00008

Colzato, L. S., Wildenberg, W. P. M. van den, Zmigrod, S., & Hommel, B. (2013). Action video gaming and cognitive control: Playing first person shooter games is associated with improvement in working memory but not action inhibition. *Psychological Research*, *77*(2), 234–239. https://doi.org/10.1007/s00426-012-0415-2

Conati, C., Jaques, N., & Muir, M. (2013). Understanding Attention to Adaptive Hints in Educational Games: An Eye-Tracking Study. *International Journal of Artificial Intelligence in Education*, *23*(1), 136–161. https://doi.org/10.1007/s40593-013-0002-8

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers & Education*, *59*(2), 661–686. https://doi.org/10.1016/j.compedu.2012.03.004

Corbetta, M., & Shulman, G. L. (1998). Human cortical mechanisms of visual attention during orienting and search. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, *353*(1373), 1353–1362. https://doi.org/10.1098/rstb.1998.0289

Cowan, N., AuBuchon, A. M., Gilchrist, A. L., Ricker, T. J., & Saults, J. S. (2011). Age Differences in Visual Working Memory Capacity: Not Based on Encoding Limitations. *Developmental Science*, *14*(5), 1066–1074. https://doi.org/10.1111/j.1467-7687.2011.01060.x

Cromby, J. (2007). Integrating Social Science with Neuroscience: Potentials and Problems. *BioSocieties*, *2*(2), 149–169. https://doi.org/10.1017/S1745855207005224

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience* (1st ed.). Harper [and] Row.

Culham, J. C., Brandt, S. A., Cavanagh, P., Kanwisher, N. G., Dale, A. M., & Tootell, R. B. H. (1998). Cortical fMRI Activation Produced by Attentive Tracking of Moving Targets. *Journal of Neurophysiology*, *80*(5), 2657–2670. https://doi.org/10.1152/jn.1998.80.5.2657

Davachi, L., & Dobbins, I. G. (2008). Declarative Memory. *Current Directions in Psychological Science*, *17*(2), 112–118. https://doi.org/10.1111/j.1467-8721.2008.00559.x

Davidson, J. (1983). *MathBlaster* [English]. JUMPSTART GAMES, INC. http://www.mathblaster.com

Dayan, P. (1999). Unsupervised learning. In R. A. Wilson & F. C. Keil (Eds.), *The MIT encyclopedia of the cognitive sciences*. MIT Press. http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=86058

Delanty, G., & Strydom, P. (Eds.). (2003). *Philosophies of social science: The classic and contemporary readings*. Open University.

D'Esposito, M., & Postle, B. R. (2015). The Cognitive Neuroscience of Working Memory. *Annual Review of Psychology*, *66*(1), 115–142. https://doi.org/10.1146/annurev-psych-010814-015031

Deterding, S. (2015). The Lens of Intrinsic Skill Atoms: A Method for Gameful Design. *Human–Computer Interaction*, *30*(3–4), 294–335. https://doi.org/10.1080/07370024.2014.993471

Deterding, S., Björk, S. L., Nacke, L. E., Dixon, D., & Lawley, E. (2013). Designing Gamification: Creating Gameful and Playful Experiences. *CHI '13 Extended Abstracts on Human Factors in Computing Systems*, 3263–3266. https://doi.org/10.1145/2468356.2479662

Devan, B. D., & White, N. M. (1999). Parallel Information Processing in the Dorsal Striatum: Relation to Hippocampal Function. *Journal of Neuroscience*, *19*(7), 2789–2798. https://doi.org/10.1523/JNEUROSCI.19-07-02789.1999

Devonshire, I. M., Davis, J., Fairweather, S., Highfield, L., Thaker, C., Walsh, A., Wilson, R., & Hathway, G. J. (2014). Risk-Based Learning Games Improve Long-Term Retention of Information among School Pupils. *PLoS ONE*, *9*(7). https://doi.org/10.1371/journal.pone.0103640

Dikker, S., Wan, L., Davidesco, I., Kaggen, L., Oostrik, M., McClintock, J., Rowland, J., Michalareas, G., Van Bavel, J. J., Ding, M., & Poeppel, D. (2017). Brain-to-Brain Synchrony Tracks Real-World Dynamic Group Interactions in the Classroom. *Current Biology*, *27*(9), 1375–1380. https://doi.org/10.1016/j.cub.2017.04.002

Dixon, J. D. (1984). Factorization and Primality Tests. *The American Mathematical Monthly*, *91*(6), 333–352. https://doi.org/10.1080/00029890.1984.11971425

Doya, K. (1999). What are the computations of the cerebellum, the basal ganglia and the cerebral cortex? *Neural Networks*, *12*(7), 961–974. https://doi.org/10.1016/S0893-6080(99)00046-5

Druckman, J. N., & Kam, C. D. (2011). Students as Experimental Participants. In J. N. Druckman, D. P. Green, J. H. Kuklinski, & A. Lupia (Eds.), *Cambridge Handbook of Experimental Political Science* (pp. 41–57). Cambridge University Press. https://doi.org/10.1017/CBO9780511921452.004

Dye, M. W. G., & Bavelier, D. (2010). Differential development of visual attention skills in school-age children. *Vision Research*, *50*(4), 452–459. https://doi.org/10.1016/j.visres.2009.10.010

Dye, M. W. G., Green, C. S., & Bavelier, D. (2009a). The development of attention skills in action video game players. *Neuropsychologia*, *47*(8–9), 1780–1789. https://doi.org/10.1016/j.neuropsychologia.2009.02.002

Dye, M. W. G., Green, C. S., & Bavelier, D. (2009b). Increasing speed of processing with action video games. *Current Directions in Psychological Science*, *18*(6), 321–326. https://doi.org/10.1111/j.1467-8721.2009.01660.x

Easton, A., Douchamps, V., Eacott, M., & Lever, C. (2012). A specific role for septohippocampal acetylcholine in memory? *Neuropsychologia*, *50*(13), 3156–3168. https://doi.org/10.1016/j.neuropsychologia.2012.07.022

Eichenbaum, H. (2004). Hippocampus: Cognitive Processes and Neural Representations that Underlie Declarative Memory. *Neuron*, *44*(1), 109–120. https://doi.org/10.1016/j.neuron.2004.08.028

Endress, A. D., Korjoukov, I., & Bonatti, L. L. (2017). Category-based grouping in working memory and multiple object tracking. *Visual Cognition*, *25*(9–10), 868–887. https://doi.org/10.1080/13506285.2017.1349229

Endsley, M. R. (2000). Theoretical Underpinnings of Situation Awareness: A Critical Review. In M. R. Endsley & D. J. Garland (Eds.), *Situation awareness: Analysis and measurement*. Lawrence Erlbaum Associates.

Engelkamp, J., Seiler, K. H., & Zimmer, H. D. (2004). Memory for actions: Item and relational information in categorized lists. *Psychological Research*, *69*(1–2), 1–10. https://doi.org/10.1007/s00426-003-0160-7

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review*, *100*(3), 363–406. https://doi.org/10.1037/0033-295X.100.3.363

ESA. (2019). *2019 Essential Facts About the Computer and Video Game Industry* (The Entertainment Software Association, p. 24) [Report]. Entertainment Software Association (ESA). https://www.theesa.com/esa-research/2019-essential-facts-about-the-computer-and-video-game-industry/

Fair, D. A., Cohen, A. L., Power, J. D., Dosenbach, N. U. F., Church, J. A., Miezin, F. M., Schlaggar, B. L., & Petersen, S. E. (2009). Functional Brain Networks Develop from a “Local to Distributed” Organization. *PLOS Computational Biology*, *5*(5), e1000381. https://doi.org/10.1371/journal.pcbi.1000381

Feng, J., Spence, I., & Pratt, J. (2007). Playing an action video game reduces gender differences in spatial cognition. *Psychological Science*, *18*(10), 850–855. https://doi.org/10.1111/j.1467-9280.2007.01990.x

Feria, C. S. (2012). The Effects of Distractors in Multiple Object Tracking are Modulated by the Similarity of Distractor and Target Features. *Perception*, *41*(3), 287–304. https://doi.org/10.1068/p7053

Fiorillo, C. D., Tobler, P. N., & Schultz, W. (2003). Discrete Coding of Reward Probability and Uncertainty by Dopamine Neurons. *Science*, *299*(5614), 1898–1902. https://doi.org/10.1126/science.1077349

Fisher, J. E. (1976). Competition and Gaming: An Experimental Study. *Simulation & Games*, 321–328. https://doi.org/10.1177/003755007673007

Folia, V., & Petersson, K. M. (2014). Implicit structured sequence learning: An fMRI study of the structural mere-exposure effect. *Frontiers in Psychology*, *5*, 41. https://doi.org/10.3389/fpsyg.2014.00041

Fougnie, D. (2008). The Relationship between Attention and Working Memory. In N. B. Johansen (Ed.), *New research on short-term memory* (pp. 1–45). Nova Science Publishers, Inc.

Fougnie, D., & Marois, R. (2006). Distinct Capacity Limits for Attention and Working Memory: Evidence from Attentive Tracking and Visual Working Memory Paradigms. *Psychological Science*, *17*(6), 526–534.

Franz, L. (2012). The Allocation of Attention to Learning of Goal-Directed Actions: A Cognitive Neuroscience Framework Focusing on the Basal Ganglia. *Frontiers in Psychology*, *3*. https://doi.org/10.3389/fpsyg.2012.00535

Fullerton, T. (2019). *Game design workshop: A playcentric approach to creating innovative games* (Fourth edition). Taylor & Francis, CRC Press.

Funk, S. C., & Dickson, K. L. (2011). Multiple-Choice and Short-Answer Exam Performance in a College Classroom. *Teaching of Psychology*, *38*(4), 273–277. https://doi.org/10.1177/0098628311421329

Gabrieli, J. D. E. (2016). The promise of educational neuroscience: Comment on Bowers (2016). *Psychological Review*, *123*(5), 613–619. https://doi.org/10.1037/rev0000034

Gallese †, V., & Lakoff, G. (2005). The Brain's concepts: The role of the Sensory-motor system in conceptual knowledge. *Cognitive Neuropsychology*, *22*(3–4), 455–479. https://doi.org/10.1080/02643290442000310

GameTrack (IFSE/Ipsos Connect). (2017). *GameTrack Digest Q4, 2017* (Quarter 4, 2017). https://www.isfe.eu/publication/gametrack-digest-q4-2017/

Garris, R., Ahlers, R., & Driskell, J. E. (2002). Games, Motivation, and Learning: A Research and Practice Model. *Simulation & Gaming*, *33*(4), 441–467. https://doi.org/10.1177/1046878102238607

Gazzard, A. (2011). Unlocking the Gameworld: The Rewards of Space and Time in Videogames. *Game Studies*, *11*(1). http://gamestudies.org/1101/articles/gazzard_alison

Ghahramani, Z. (2004). Unsupervised Learning. In O. Bousquet, U. von Luxburg, & G. Rätsch (Eds.), *Advanced Lectures on Machine Learning: ML Summer Schools 2003, Canberra, Australia, February 2—14, 2003, Tübingen, Germany, August 4—16, 2003, Revised Lectures* (pp. 72–112). Springer. https://doi.org/10.1007/978-3-540-28650-9_5

Giovannini, M. G., Rakovska, A., Benton, R. S., Pazzagli, M., Bianchi, L., & Pepeu, G. (2001). Effects of novelty and habituation on acetylcholine, GABA, and glutamate release from the frontal cortex and hippocampus of freely moving rats. *Neuroscience*, *106*(1), 43–53. https://doi.org/10.1016/S0306-4522(01)00266-4

Gove, M. (2011, June 29). *Michael Gove speaks to the Royal Society on maths and science*. GOV.UK. https://www.gov.uk/government/speeches/michael-gove-speaks-to-the-royal-society-on-maths-and-science

Gozli, D. G., Bavelier, D., & Pratt, J. (2014). The effect of action video game playing on sensorimotor learning: Evidence from a movement tracking task. *Human Movement Science*, *38*, 152–162. https://doi.org/10.1016/j.humov.2014.09.004

Green, C. Shawn. (2014). The Perceptual and Cognitive Effects of Action Video Game Experience. In F. Blumberg (Ed.), *Learning by playing: Video gaming in education* (pp. 29–41). Oxford University Press.

Green, C. Shawn, & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature*, *423*(6939), 534–537. https://doi.org/10.1038/nature01647

Green, C. Shawn, & Bavelier, D. (2006a). Enumeration versus multiple object tracking: The case of action video game players. *Cognition*, *101*(1), 217–245. https://doi.org/10.1016/j.cognition.2005.10.004

Green, C. Shawn, & Bavelier, D. (2006b). Effect of Action Video Games on the Spatial Distribution of Visuospatial Attention. *Journal of Experimental Psychology. Human Perception and Performance*, *32*(6), 1465–1478. https://doi.org/10.1037/0096-1523.32.6.1465

Green, Sugarman, M. A., Medford, K., Klobusicky, E., & Bavelier, D. (2012). The effect of action video game experience on task-switching. *Computers in Human Behavior*, *28*(3), 984–994. https://doi.org/10.1016/j.chb.2011.12.020

Greenfield, P. M. (2009). Technology and Informal Education: What Is Taught, What Is Learned. *Science*, *323*(5910), 69–71. https://doi.org/10.1126/science.1167190

Gritton, H. J., Howe, W. M., Mallory, C. S., Hetrick, V. L., Berke, J. D., & Sarter, M. (2016). Cortical cholinergic signaling controls the detection of cues. *Proceedings of the National Academy of Sciences*, *113*(8), E1089–E1097. https://doi.org/10.1073/pnas.1516134113

Habgood, M. P. J., & Ainsworth, S. E. (2011). Motivating Children to Learn Effectively: Exploring the Value of Intrinsic Integration in Educational Games. *Journal of the Learning Sciences*, *20*(2), 169–206. https://doi.org/10.1080/10508406.2010.508029

Hainey, T., Connolly, T. M., Boyle, E. A., Wilson, A., & Razak, A. (2016). A systematic literature review of games-based learning empirical evidence in primary education. *Computers & Education*, *102*, 202–223. https://doi.org/10.1016/j.compedu.2016.09.001

Han, H., Soylu, F., & Anchan, D. M. (2019). Connecting levels of analysis in educational neuroscience: A review of multi-level structure of educational neuroscience with concrete examples. *Trends in Neuroscience and Education*, *17*, 100113. https://doi.org/10.1016/j.tine.2019.100113

Hanel, P. H. P., & Vione, K. C. (2016). Do Student Samples Provide an Accurate Estimate of the General Public? *PLoS ONE*, *11*(12). https://doi.org/10.1371/journal.pone.0168354

Harris, D. J., Wilson, M. R., Crowe, E. M., & Vine, S. J. (2020). Examining the roles of working memory and visual attention in multiple object tracking expertise. *Cognitive Processing*, *21*(2), 209–222. https://doi.org/10.1007/s10339-020-00954-y

Hasselmo, M. E. (2006). The Role of Acetylcholine in Learning and Memory. *Current Opinion in Neurobiology*, *16*(6), 710–715. https://doi.org/10.1016/j.conb.2006.09.002

Heil, M., Rolke, B., Engelkamp, J., Rosler, F., Ozcan, M., & Hennighausen, E. (1999). Event-related Brain Potentials During Recognition of Ordinary and Bizarre Action Phrases Following Verbal and Subject-performed Encoding Conditions. *European Journal of Cognitive Psychology*, *11*(2), 261–280. https://doi.org/10.1080/713752313

Heyes, C. (2012). What's social about social learning? *Journal of Comparative Psychology*, *126*(2), 193–202. https://doi.org/10.1037/a0025180

Horowitz, T. S., Klieger, S. B., Fencsik, D. E., Yang, K. K., Alvarez, G. A., & Wolfe, J. M. (2007). Tracking unique objects. *Perception & Psychophysics*, *69*(2), 172–184. https://doi.org/10.3758/BF03193740

Horvath, J. C., Lodge, J. M., & Hattie, J. (Eds.). (2017). *From the laboratory to the classroom: Translating science of learning for teachers*. Routledge iTaylor & Francis Group.

Howard-Jones, P. (2008a). Education and neuroscience. *Educational Research*, *50*(2), 119–122. https://doi.org/10.1080/00131880802082492

Howard-Jones, P. (2008b). Philosophical Challenges for Researchers at the Interface between Neuroscience and Education. *Journal of Philosophy of Education*, *42*(3–4), 361–380. https://doi.org/10.1111/j.1467-9752.2008.00649.x

Howard-Jones, P. (2010). *Introducing neuroeducational research: Neuroscience, education and the brain from contexts to practice*. Routledge.

Howard-Jones, P. A., & Demetriou, S. (2009). Uncertainty and engagement with learning games. *Instructional Science*, *37*(6), 519–536. https://doi.org/10.1007/s11251-008-9073-6

Howard-Jones, P. A., & Jay, T. (2016). Reward, learning and games. *Current Opinion in Behavioral Sciences*, *10*, 65–72. https://doi.org/10.1016/j.cobeha.2016.04.015

Howard-Jones, P. A., Jay, T., Mason, A., & Jones, H. (2016). Gamification of Learning Deactivates the Default Mode Network. *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.01891

Howard-Jones, P. A., Varma, S., Ansari, D., Butterworth, B., De Smedt, B., Goswami, U., Laurillard, D., & Thomas, M. S. C. (2016). The principles and practices of educational neuroscience: Comment on Bowers (2016). *Psychological Review*, *123*(5), 620–627. https://doi.org/10.1037/rev0000036

Howard-Jones, P., Demetriou, S., Bogacz, R., Yoo, J. H., & Leonards, U. (2011). Toward a Science of Learning Games. *Mind, Brain, and Education*, *5*(1), 33–41. https://doi.org/10.1111/j.1751-228X.2011.01108.x

Howe, P. D., Horowitz, T. S., Morocz, I. A., Wolfe, J., & Livingstone, M. S. (2009). Using fMRI to distinguish components of the multiple object tracking task. *Journal of Vision*, *9*(4), 10.1. https://doi.org/10.1167/9.4.10

Howe, W., Berry, A. S., Francois, J., Gilmour, G., Carp, J. M., Tricklebank, M., Lustig, C., & Sarter, M. (2013). Prefrontal Cholinergic Mechanisms Instigating Shifts from Monitoring for Cues to Cue-Guided Performance: Converging Electrochemical and fMRI Evidence from Rats and Humans. *The Journal of Neuroscience*, *33*(20), 8742–8752. https://doi.org/10.1523/JNEUROSCI.5809-12.2013

Hu, L. M., Lyu, C., Zhang, X. M., & Wei, L. Q. (2018). The effect of identity switch in multiple identity tracking. *Acta Psychologica Sinica*, *50*(1), 9–27.

Huang, D., Zhang, Y., & Zhang, K. (2014). The Effects of the Relationships Between Object Features on Multiple-Identity Tracking. *Experimental Psychology*, *61*(5), 340–346. https://doi.org/10.1027/1618-3169/a000253

Huang, L., Mo, L., & Li, Y. (2012). Measuring the interrelations among multiple paradigms of visual attention: An individual differences approach. *Journal of Experimental Psychology: Human Perception and Performance*, *38*(2), 414–428. https://doi.org/10.1037/a0026314

Hudson, C., Howe, P. D. L., & Little, D. R. (2012). Hemifield Effects in Multiple Identity Tracking. *PLOS ONE*, *7*(8), e43796. https://doi.org/10.1371/journal.pone.0043796

Huizinga, J. (1938). *Homo ludens a study of the play-element in culture* (Unabridged reprint of the first edition). Routledge & K. Paul.

Hulme, C., & Roodenrys, S. (1995). The role of long-term memory mechanisms in memory span. *British Journal of Psychology*, *86*(4), 527. https://doi.org/10.1111/j.2044-8295.1995.tb02570.x

Hunicke, R., LeBlanc, M., & Zubek, R. (2004). MDA: A Formal Approach to Game Design and Game Research. *Proceedings of the AAAI Workshop on Challenges in Games AI*, 5.

Illeris, K. (2007). *How we learn: Learning and non-learning in school and beyond* (English ed). Routledge.

Illeris, K. (2012). Learning and cognition. In P. Jarvis & M. H. Watts (Eds.), *The Routledge international handbook of learning* (pp. 18–27). Routledge.

Itti, L., & Koch, C. (2001). Computational modelling of visual attention. *Nature Reviews Neuroscience*, *2*(3), 194–203. https://doi.org/10.1038/35058500

Jarvis, P., & Parker, S. (Eds.). (2007). *Human learning: An holistic approach*. Routledge.

Jay, T., Habgood, J., Mees, M., & Howard-Jones, P. (2019). Game-Based Training to Promote Arithmetic Fluency. *Frontiers in Education*, *4*. https://doi.org/10.3389/feduc.2019.00118

Joldersma, C. W. (2018). What Can Philosophers of Education Contribute to the Conversations that Connect Education and Neuroscience? In C. W. Joldersma (Ed.), *Neuroscience and education: A philosophical appraisal* (pp. 1–12). Routledge. http://www.vlebooks.com/vleweb/product/openreader?id=none&isbn=9781317623113

Jovicich, J., Peters, R. J., Koch, C., Braun, J., Chang, L., & Ernst, T. (2001). Brain Areas Specific for Attentional Load in a Motion-Tracking Task. *Journal of Cognitive Neuroscience*, *13*(8), 1048–1058. https://doi.org/10.1162/089892901753294347

Juul, J. (2005). *Half-real: Video games between real rules and fictional worlds*. MIT Press.

Kahana, M., & Loftus, G. (1999). Response Time versus Accuracy in Human Memory. In R. J. Sternberg (Ed.), *The nature of cognition* (pp. 323–384). MIT Press.

Kandel, E. R., & Hawkins, R. D. (1992). The biological basis of learning and individuality. *Scientific American*, *267*(3), 78–86.

Karatekin, C., Marcus, D. J., & Couperus, J. W. (2007). Regulation of cognitive resources during sustained attention and working memory in 10-year-olds and adults. *Psychophysiology*, *44*(1), 128–144. https://doi.org/10.1111/j.1469-8986.2006.00477.x

Karle, J. W., Watter, S., & Shedden, J. M. (2010). Task switching in video game players: Benefits of selective attention but not resistance to proactive interference. *Acta Psychologica*, *134*(1), 70–78. https://doi.org/10.1016/j.actpsy.2009.12.007

Karlsson Wirebring, L., Wiklund-Hörnqvist, C., Eriksson, J., Andersson, M., Jonsson, B., & Nyberg, L. (2015). Lesser Neural Pattern Similarity across Repeated Tests Is Associated with Better Long-Term Memory Retention. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *35*(26), 9595–9602. https://doi.org/10.1523/JNEUROSCI.3550-14.2015

Kinzer, C. K., Hoffman, D. L., Türkay, S., Günbas, N., Chantes, P., Dvorkin, T., & Chaiwinij, A. (2012). The Impact of Choice and Feedback on Learning, Motivation, and Performance in an Educational Video Game. *Proceedings of the Games, Learning, and Society Conference*, *2*, 175–181.

Kirriemuir, J., & McFarlane, A. (2004). *Literature review in games and learning: A report for NESTA Futurelab*. NESTA Futurelab. http://hal.archives-ouvertes.fr/docs/00/19/04/53/PDF/kirriemuir-j-2004-r8.pdf

Klimesch, W., Doppelmayr, M., & Hanslmayr, S. (2006). Upper alpha ERD and absolute power: Their meaning for memory performance. In C. Neuper & W. Klimesch (Eds.), *Progress in Brain Research* (Vol. 159, pp. 151–165). Elsevier. https://doi.org/10.1016/S0079-6123(06)59010-7

Klimesch, W., Schack, B., & Sauseng, P. (2005). The functional significance of theta and upper alpha oscillations. *Experimental Psychology*, *52*(2), 99–108. https://doi.org/10.1027/1618-3169.52.2.99

Klinkenberg, I., Sambeth, A., & Blokland, A. (2011). Acetylcholine and attention. *Behavioural Brain Research*, *221*(2), 430–442. https://doi.org/10.1016/j.bbr.2010.11.033

Knudsen, E. I. (1994). Supervised learning in the brain. *Journal of Neuroscience*, *14*(7), 3985–3997.

Knutson, B., Adams, C. M., Fong, G. W., & Hommer, D. (2001). Anticipation of Increasing Monetary Reward Selectively Recruits Nucleus Accumbens. *The Journal of Neuroscience*, *21*(16), RC159–RC159.

Koepp, M. J., Gunn, R. N., Lawrence, A. D., Cunningham, V. J., Dagher, A., Jones, T., Brooks, D. J., Bench, C. J., & Grasby, P. M. (1998). Evidence for striatal dopamine release during a video game. *Nature*, *393*(6682), 266–268. https://doi.org/10.1038/30498

Kolb, B., & Whishaw, I. Q. (1998). Brain Plasticity and Behavior. *Annual Review of Psychology*, *49*(1), 43–64. https://doi.org/10.1146/annurev.psych.49.1.43

Koziol, L. F., Budding, D., Andreasen, N., D'Arrigo, S., Bulgheroni, S., Imamizu, H., Ito, M., Manto, M., Marvel, C., Parker, K., Pezzulo, G., Ramnani, N., Riva, D., Schmahmann, J., Vandervert, L., & Yamazaki, T. (2014). Consensus Paper: The Cerebellum's Role in Movement and Cognition. *The Cerebellum*, *13*(1), 151–177. https://doi.org/10.1007/s12311-013-0511-x

Kukolja, J., Thiel, C. M., & Fink, G. R. (2009). Cholinergic Stimulation Enhances Neural Activity Associated with Encoding but Reduces Neural Activity Associated with Retrieval in Humans. *The Journal of Neuroscience*, *29*(25), 8119–8128. https://doi.org/10.1523/JNEUROSCI.0203-09.2009

Kyllonen, P., & Zu, J. (2016). Use of Response Time for Measuring Cognitive Ability. *Journal of Intelligence*, *4*(4), 14. https://doi.org/10.3390/jintelligence4040014

Li, J., Oksama, L., & Hyönä, J. (2019). Model of Multiple Identity Tracking (MOMIT) 2.0: Resolving the serial vs. parallel controversy in tracking. *Cognition*, *182*, 260–274. https://doi.org/10.1016/j.cognition.2018.10.016

Lieberman, D. A. (2006). What can we learn from playing interactive games? In P. Vorderer & J. Bryant (Eds.), *Playing Video Games: Motives, Responses, and Consequences.* (pp. 379–397). Taylor and Francis. http://public.eblib.com/choice/publicfullrecord.aspx?p=446619

Lindemann, O., Abolafia, J. M., Girardi, G., & Bekkering, H. (2007). Getting a grip on numbers: Numerical magnitude priming in object grasping. *Journal of Experimental Psychology: Human Perception and Performance*, *33*(6), 1400–1409. https://doi.org/10.1037/0096-1523.33.6.1400

Lisón, J. F., Cebolla, A., Guixeres, J., Álvarez-Pitti, J., Escobar, P., Bruñó, A., Lurbe, E., Alcañiz, M., & Baños, R. (2015). Competitive active video games: Physiological and psychological responses in children and adolescents. *Paediatrics & Child Health*, *20*(7), 373–376.

Little, J. L., & Bjork, E. L. (2016). Multiple-choice pretesting potentiates learning of related information. *Memory & Cognition*, *44*(7), 1085–1101. https://doi.org/10.3758/s13421-016-0621-z

Liu, C. C., & Watanabe, T. (2012). Accounting for speed–accuracy tradeoff in perceptual learning. *Vision Research*, *61*, 107–114. https://doi.org/10.1016/j.visres.2011.09.007

Liu, T., Chen, W., Liu, C. H., & Fu, X. (2012a). Benefits and costs of uniqueness in multiple object tracking: The role of object complexity. *Vision Research*, *66*, 31–38. https://doi.org/10.1016/j.visres.2012.06.009

Liu, T., Chen, W., Liu, C. H., & Fu, X. (2012b). Benefits and costs of uniqueness in multiple object tracking: The role of object complexity. *Vision Research*, *66*, 31–38. https://doi.org/10.1016/j.visres.2012.06.009

Lochner, M. J., & Trick, L. M. (2014). Multiple-object tracking while driving: The multiple-vehicle tracking task. *Attention, Perception & Psychophysics*, *76*(8), 2326–2345. https://doi.org/10.3758/s13414-014-0694-3

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review*, 492–527.

Lyu, C., Hu, S., Wei, L., Zhang, X., & Talhelm, T. (2015). Brain Activation of Identity Switching in Multiple Identity Tracking Task. *PLOS ONE*, *10*(12), e0145489. https://doi.org/10.1371/journal.pone.0145489

Macfarlane, B. (2009). *Researching with integrity: The ethics of academic enquiry*. Routledge.

MacLeod, C. M., & Nelson, T. O. (1984). Response latency and response accuracy as measures of memory. *Acta Psychologica*, *57*(3), 215–235. https://doi.org/10.1016/0001-6918(84)90032-5

Maguire, E. A., Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S. J., & Frith, C. D. (2000). Navigation-related structural change in the hippocampi of taxi drivers. *Proceedings of the National Academy of Sciences*, *97*(8), 4398–4403. https://doi.org/10.1073/pnas.070039597

Makovski, T., & Jiang, Y. V. (2009a). Feature binding in attentive tracking of distinct objects. *Visual Cognition*, *17*(1–2), 180–194. https://doi.org/10.1080/13506280802211334

Makovski, T., & Jiang, Y. V. (2009b). The role of visual working memory in attentive tracking of unique objects. *Journal of Experimental Psychology. Human Perception and Performance*, *35*(6), 1687–1697. https://doi.org/10.1037/a0016453

Malone, T. W. (1981). Toward a theory of intrinsically motivating instruction. *Cognitive Science*, *5*(4), 333–369. https://doi.org/10.1016/S0364-0213(81)80017-1

Malone, T. W., & Lepper, M. R. (1987). Making learning fun: A taxonomy of intrinsic motivations for learning. In R. E. Snow & M. J. Farr (Eds.), *Aptitude, learning, and instruction: Vol. Volume 3: Conative and Affective Process Analyses* (pp. 223–253). Lawrence Erlbaum Associates.

Marsh, E. J., Roediger, H. L., Bjork, R. A., & Bjork, E. L. (2007). The memorial consequences of multiple-choice testing. *Psychonomic Bulletin & Review*, *14*(2), 194–199. https://doi.org/10.3758/BF03194051

Mason, A., Farrell, S., Howard-Jones, P., & Ludwig, C. J. H. (2017). The role of reward and reward uncertainty in episodic memory. *Journal of Memory and Language*, *96*, 62–77. https://doi.org/10.1016/j.jml.2017.05.003

Matsuno, T., & Tomonaga, M. (2006). Visual search for moving and stationary items in chimpanzees (Pan troglodytes) and humans (Homo sapiens). *Behavioural Brain Research*, *172*(2), 219–232. https://doi.org/10.1016/j.bbr.2006.05.004

Mayer, R. E. (2015). On the Need for Research Evidence to Guide the Design of Computer Games for Learning. *Educational Psychologist*, *50*(4), 349–353. https://doi.org/10.1080/00461520.2015.1133307

Mayer, R. E. (2019). Computer Games in Education. *Annual Review of Psychology*, *70*(1), 531–549. https://doi.org/10.1146/annurev-psych-010418-102744

Memmert, D., Simons, D. J., & Grimme, T. (2009). The relationship between visual attention and expertise in sports. *Psychology of Sport and Exercise*, *10*(1), 146–151. https://doi.org/10.1016/j.psychsport.2008.06.002

Meyerhoff, H. S., Papenmeier, F., & Huff, M. (2017). Studying visual attention using the multiple object tracking paradigm: A tutorial review. *Attention Perception & Psychophysics*, *79*(5), 1255–1274. https://doi.org/10.3758/s13414-017-1338-1

Micheau, J., & Marighetto, A. (2011). Acetylcholine and memory: A long, complex and chaotic but still living relationship. *Behavioural Brain Research*, *221*(2), 424–429. https://doi.org/10.1016/j.bbr.2010.11.052

Moors, A., & De Houwer, J. (2006). Automaticity: A Theoretical and Conceptual Analysis. *Psychological Bulletin*, *132*(2), 297–326. https://doi.org/10.1037/0033-2909.132.2.297

Mora, A., Riera, D., Gonzalez, C., & Arnedo-Moreno, J. (2015). A Literature Review of Gamification Design Frameworks. *2015 7th International Conference on Games and Virtual Worlds for Serious Applications (VS-Games)*, 1–8. https://doi.org/10.1109/VS-GAMES.2015.7295760

Morton, J., & Frith, U. (1995). Causal modeling: A structural approach to developmental psychopathology. In *Developmental psychopathology, Vol. 1: Theory and methods* (pp. 357–390). John Wiley & Sons.

Murphy, S. C. (2004). 'Live in Your World, Play in Ours': The Spaces of Video Game Identity. *Journal of Visual Culture*, *3*(2), 223–238. https://doi.org/10.1177/1470412904044801

Murray, J. H. (1998). *Hamlet on the holodeck: The future of narrative in cyberspace*. MIT Press.

National Mathematics Advisory Panel. (2008). *Foundations for Success: The Final Report of the National Mathematics Advisory Panel* (p. 90). U.S. Department of Education.

Nelson, R. A., & Strachan, I. (2009). Action and Puzzle Video Games Prime Different Speed/Accuracy Tradeoffs. *Perception*, *38*(11), 1678–1687. https://doi.org/10.1068/p6324

Nieder, A., & Dehaene, S. (2009). Representation of Number in the Brain. *Annual Review of Neuroscience*, *32*(1), 185–208. https://doi.org/10.1146/annurev.neuro.051508.135550

Nieuwenhuis, S., Heslenfeld, D. J., Alting von Geusau, N. J., Mars, R. B., Holroyd, C. B., & Yeung, N. (2005). Activity in human reward-sensitive brain areas is strongly context dependent. *NeuroImage*, *25*(4), 1302–1309. https://doi.org/10.1016/j.neuroimage.2004.12.043

Nilsson, L.-G. (1987). Motivated memory: Dissociation between performance data and subjective reports. *Psychological Research*, *49*(2), 183–188. https://doi.org/10.1007/BF00308685

Nishikawa, K. A., & Jaeger, J. (2011). A Computer Simulation Comparing the Incentive Structures of Dictatorships and Democracies. *Journal of Political Science Education*, *7*(2), 135–142. https://doi.org/10.1080/15512169.2011.564915

Noyes, J. M., & Garland, K. J. (2008). Computer- vs. paper-based tasks: Are they equivalent? *Ergonomics*, *51*(9), 1352–1375. https://doi.org/10.1080/00140130802170387

Oberauer, K. (2019). Working Memory and Attention – A Conceptual Analysis and Review. *Journal of Cognition*, *2*(1), 36. https://doi.org/10.5334/joc.58

O'Hearn, K., Hoffman, J. E., & Landau, B. (2010). Developmental profiles for multiple object tracking and spatial memory: Normally developing preschoolers and people with Williams syndrome. *Developmental Science*, *13*(3), 430–440. https://doi.org/10.1111/j.1467-7687.2009.00893.x

Oja, E. (2002). Unsupervised learning in neural computation. *Theoretical Computer Science*, *287*(1), 187–207. https://doi.org/10.1016/S0304-3975(02)00160-3

Oksama, L., & Hyönä, J. (2004). Is multiple object tracking carried out automatically by an early vision mechanism independent of higher-order cognition? An individual difference approach. *Visual Cognition*, *11*(5), 631–671. https://doi.org/10.1080/13506280344000473

Oksama, L., & Hyönä, J. (2008a). Dynamic binding of identity and location information: A serial model of multiple identity tracking. *Cognitive Psychology*, *56*(4), 237–283. https://doi.org/10.1016/j.cogpsych.2007.03.001

Oksama, L., & Hyönä, J. (2008b). Dynamic binding of identity and location information: A serial model of multiple identity tracking. *Cognitive Psychology*, *56*(4), 237–283. https://doi.org/10.1016/j.cogpsych.2007.03.001

Oksama, L., & Hyönä, J. (2016). Position tracking and identity tracking are separate systems: Evidence from eye movements. *Cognition*, *146*, 393–409. https://doi.org/10.1016/j.cognition.2015.10.016

Palaus, M., Marron, E. M., Viejo-Sobera, R., & Redolar-Ripoll, D. (2017). Neural Basis of Video Gaming: A Systematic Review. *Frontiers in Human Neuroscience*, *11*. https://doi.org/10.3389/fnhum.2017.00248

Papastergiou, M. (2009). Digital Game-Based Learning in high school Computer Science education: Impact on educational effectiveness and student motivation. *Computers & Education*, *52*(1), 1–12. https://doi.org/10.1016/j.compedu.2008.06.004

Parikh, V., & Sarter, M. (2008). Cholinergic mediation of attention: Contributions of phasic and tonic increases in prefrontal cholinergic activity. *Annals of the New York Academy of Sciences*, *1129*, 225–235. https://doi.org/10.1196/annals.1417.021

Pashler, H. E. (1998). *The psychology of attention*. The MIT Press.

Phelps, E. A. (2004). Human emotion and memory: Interactions of the amygdala and hippocampal complex. *Current Opinion in Neurobiology*, *14*(2), 198–202. https://doi.org/10.1016/j.conb.2004.03.015

Phillips, D. C., & Burbules, N. C. (2000). *Postpositivism and educational research*. Rowman & Littlefield Publishers.

Picciotto, M. R., Higley, M. J., & Mineur, Y. S. (2012). Acetylcholine as a neuromodulator: Cholinergic signaling shapes nervous system function and behavior. *Neuron*, *76*(1), 116–129. https://doi.org/10.1016/j.neuron.2012.08.036

Pinto, Y., Howe, P. D. L., Cohen, M. A., & Horowitz, T. S. (2010). The more often you see an object, the easier it becomes to track it. *Journal of Vision*, *10*(10), 4–4. https://doi.org/10.1167/10.10.4

Pinto, Y., Scholte, H. S., & Lamme, V. a. F. (2012). Tracking Moving Identities: After Attending the Right Location, the Identity Does Not Come for Free. *PLOS ONE*, *7*(8), e42929. https://doi.org/10.1371/journal.pone.0042929

Plass, J. L., Homer, B. D., & Kinzer, C. K. (2015). Foundations of Game-Based Learning. *Educational Psychologist*, *50*(4), 258–283. https://doi.org/10.1080/00461520.2015.1122533

Popper, K. R. (1969). *Conjectures and refutations: The growth of scientific knowledge* (3rd ed. (revised)). Routledge & K. Paul.

Porion, A., Aparicio, X., Megalakaki, O., Robert, A., & Baccino, T. (2016). The impact of paper-based versus computerized presentation on text comprehension and memorization. *Computers in Human Behavior*, *54*, 569–576. https://doi.org/10.1016/j.chb.2015.08.002

Posner, M. I., Snyder, C. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology*, *109*(2), 160–174.

Powers, K. L., Brooks, P. J., Aldrich, N. J., Palladino, M. A., & Alfieri, L. (2013). Effects of video-game play on information processing: A meta-analytic investigation. *Psychonomic Bulletin & Review*, *20*(6), 1055–1079. https://doi.org/10.3758/s13423-013-0418-z

Preece, J., Rogers, Y., & Sharp, H. (2011). *Interaction design: Beyond human-computer interaction* (3rd ed). Wiley.

Prena, K., Reed, A., Weaver, A. J., & Newman, S. D. (2018). Game Mechanics Matter: Differences in Video Game Conditions Influence Memory Performance. *Communication Research Reports*, *35*(3), 222–231. https://doi.org/10.1080/08824096.2018.1428545

Przegalińska, A. (2015). Gamification: Playing with neuroscience. In J. Kopeć & K. Pacewicz (Eds.), *Gamification: Critical approaches* (pp. 99–112). https://open.umn.edu/opentextbooks/BookDetail.aspx?bookId=329

Pylyshyn, Z. (1989). The role of location indexes in spatial perception: A sketch of the FINST spatial-index model. *Cognition*, *32*(1), 65–97. https://doi.org/10.1016/0010-0277(89)90014-0

Pylyshyn, Z. W., & Storm, R. W. (1988). Tracking multiple independent targets: Evidence for a parallel tracking mechanism. *Spatial Vision*, *3*(3), 179–197.

Rasch, D., & Guiard, V. (2004). The robustness of parametric statistical methods. *Psychology Science*, *46*(2), 175–208.

Raz, A., & Buhle, J. (2006). Typologies of attentional networks. *Nature Reviews Neuroscience*, *7*(5), 367–379. https://doi.org/10.1038/nrn1903

Reisner, C. (2016). On the media practice of highscoring. *Cogent Arts & Humanities*, *3*(1), 1210277. https://doi.org/10.1080/23311983.2016.1210277

Ren, D., Chen, W., Liu, C. H., & Fu, X. (2009). Identity processing in multiple-face tracking. *Journal of Vision*, *9*(5), 18–18. https://doi.org/10.1167/9.5.18

Renkl, A., & Atkinson, R. K. (2007). Interactive Learning Environments: Contemporary Issues and Trends. An Introduction to the Special Issue. *Educational Psychology Review*, *19*(3), 235. https://doi.org/10.1007/s10648-007-9052-5

Richardson, D. C., & Kirkham, N. Z. (2004). Multimodal Events and Moving Locations: Eye Movements of Adults and 6-Month-Olds Reveal Dynamic Spatial Indexing. *Journal of Experimental Psychology: General*, *133*(1), 46–62. https://doi.org/10.1037/0096-3445.133.1.46

Riesenhuber, M. (2004). An action video game modifies visual processing. *Trends in Neurosciences*, *27*(2), 72–74. https://doi.org/10.1016/j.tins.2003.11.004

Ritterfeld, U., Cuihua Shen, Hua Wang, Nocera, L., & Wee Ling Wong. (2009). Multimodality and Interactivity: Connecting Properties of Serious Games with Educational Outcomes. *CyberPsychology & Behavior*, *12*(6), 691–697. https://doi.org/10.1089/cpb.2009.0099

Roediger, H. L., & Marsh, E. J. (2005). The Positive and Negative Consequences of Multiple-Choice Testing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*(5), 1155–1159. https://doi.org/10.1037/0278-7393.31.5.1155

Röhlcke, S., Bäcklund, C., Sörman, D. E., & Jonsson, B. (2018). Time on task matters most in video game expertise. *PLOS ONE*, *13*(10), e0206555. https://doi.org/10.1371/journal.pone.0206555

Rokem, A., & Silver, M. A. (2013). The benefits of cholinergic enhancement during perceptual learning are long-lasting. *Frontiers in Computational Neuroscience*, *7*. https://doi.org/10.3389/fncom.2013.00066

Rondon, S., Sassi, F. C., & Furquim de Andrade, C. R. (2013). Computer game-based and traditional learning method: A comparison regarding students' knowledge retention. *BMC Medical Education*, *13*(1), 30. https://doi.org/10.1186/1472-6920-13-30

Rouse, R. (2005). *Game design: Theory & practice* (2nd ed). Wordware Pub.

Royden, C. S., Wolfe, J. M., & Klempen, N. (2001). Visual search asymmetries in motion and optic flow fields. *Perception & Psychophysics*, *63*(3), 436–444. https://doi.org/10.3758/BF03194410

Salen, K., & Zimmerman, E. (2004). *Rules of play: Game design fundamentals*. MIT Press.

Säljö, R. (2009). Learning, Theories of Learning, and Units of Analysis in Research. *Educational Psychologist*, *44*(3), 202–208. https://doi.org/10.1080/00461520903029030

Samuels, B. M. (2009). Can the Differences Between Education and Neuroscience be Overcome by Mind, Brain, and Education? *Mind, Brain, and Education*, *3*(1), 45–55. https://doi.org/10.1111/j.1751-228X.2008.01052.x

Sarter, M., Gehring, W. J., & Kozak, R. (2006). More attention must be paid: The neurobiology of attentional effort. *Brain Research Reviews*, *51*(2), 145–160. https://doi.org/10.1016/j.brainresrev.2005.11.002

Sarter, M., Hasselmo, M. E., Bruno, J. P., & Givens, B. (2005). Unraveling the attentional functions of cortical cholinergic inputs: Interactions between signal-driven and cognitive modulation of signal detection. *Brain Research Reviews*, *48*(1), 98–111. https://doi.org/10.1016/j.brainresrev.2004.08.006

Sarter, M., & Lustig, C. (2019). Cholinergic double duty: Cue detection and attentional control. *Current Opinion in Psychology*, *29*, 102–107. https://doi.org/10.1016/j.copsyc.2018.12.026

Sarter, M., Lustig, C., Howe, W. M., Gritton, H., & Berry, A. S. (2014). Deterministic functions of cortical acetylcholine. *European Journal of Neuroscience*, n/a-n/a. https://doi.org/10.1111/ejn.12515

Saus, E.-R., Johnsen, B. H., Eid, J., Riisem, P. K., Andersen, R., & Thayer, J. F. (2006). The Effect of Brief Situational Awareness Training in a Police Shooting Simulator: An Experimental Study. *Military Psychology*, *18*(sup1), S3–S21. https://doi.org/10.1207/s15327876mp1803s_2

Schacter, D. L., & Tulving, E. (Eds.). (1994). *Memory systems 1994*. MIT Press.

Schenk, S., Bellebaum, C., Lech, R. K., Heinen, R., & Suchan, B. (2020). Play to Win: Action Video Game Experience and Attention Driven Perceptual Exploration in Categorization Learning. *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.00933

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review*, *84*(1), 1–66. https://doi.org/10.1037/0033-295X.84.1.1

Scholl, B. J. (2009). What have we learned about attention from multiple-object tracking (and vice versa)? In *Computation, cognition, and Pylyshyn* (pp. 49–77). MIT Press.

Scholl, B. J., & Pylyshyn, Z. W. (1999). Tracking Multiple Items Through Occlusion: Clues to Visual Objecthood. *Cognitive Psychology*, *38*(2), 259–290. https://doi.org/10.1006/cogp.1998.0698

Scholl, B. J., Pylyshyn, Z. W., & Feldman, J. (2001). What is a visual object? Evidence from target merging in multiple object tracking. *Cognition*, *80*(1), 159–177. https://doi.org/10.1016/S0010-0277(00)00157-8

Scholl, B. J., Pylyshyn, Z. W., & Franconeri, S. L. (1999). When are featural and spatiotemporal properties encoded as a result of attentional allocation? *Investigative Ophthalmology & Visual Science*, *4*(40), S797.

Schultz, W. (2016). Dopamine reward prediction-error signalling: A two-component response. *Nature Reviews Neuroscience*, *17*(3), 183–195. https://doi.org/10.1038/nrn.2015.26

Schultz, W., Dayan, P., & Montague, P. R. (1997). A Neural Substrate of Prediction and Reward. *Science*, *275*(5306), 1593–1599. https://doi.org/10.1126/science.275.5306.1593

Schunk, D. H. (2012). *Learning theories: An educational perspective* (6th ed). Pearson.

Sekuler, R., McLaughlin, C., & Yotsumoto, Y. (2008). Age-Related Changes in Attentional Tracking of Multiple Moving Objects. *Perception*, *37*(6), 867–876. https://doi.org/10.1068/p5923

Shiffrin, R. M., & Schneider, W. (1977). *Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory.* https://doi.org/10.1037/0033-295x.84.2.127

Shizgal, P., & Arvanitogiannis, A. (2003). Gambling on Dopamine. *Science*, *299*(5614), 1856–1858. https://doi.org/10.1126/science.1083627

Shohamy, D., & Adcock, R. A. (2010). Dopamine and adaptive memory. *Trends in Cognitive Sciences*, *14*(10), 464–472. https://doi.org/10.1016/j.tics.2010.08.002

Shohamy, D., Myers, C. E., Kalanithi, J., & Gluck, M. A. (2008). Basal ganglia and dopamine contributions to probabilistic category learning. *Neuroscience & Biobehavioral Reviews*, *32*(2), 219–236. https://doi.org/10.1016/j.neubiorev.2007.07.008

Sloutsky, V. M. (2010). From Perceptual Categories to Concepts: What Develops? *Cognitive Science*, *34*(7), 1244–1286. https://doi.org/10.1111/j.1551-6709.2010.01129.x

Spence, I., & Feng, J. (2010). Video games and spatial cognition. *Review of General Psychology*, *14*(2), 92–104. https://doi.org/10.1037/a0019491

Squire, L. R. (1994). Declarative and Nondeclarative Memory: Multiple Brain Systems Supporting Learning and Memory. In D. L. Schacter & E. Tulving (Eds.), *Memory systems 1994* (pp. 203–231). MIT Press.

Squire, L. R. (2004). Memory systems of the brain: A brief history and current perspective. *Neurobiology of Learning and Memory*, *82*(3), 171–177. https://doi.org/10.1016/j.nlm.2004.06.005

Stein, J. (2007). The brain and learning. In P. Jarvis & S. Parker (Eds.), *Human learning: An holistic approach* (pp. 32–49). Routledge.

Stickney, E. M., Sharp, L. B., & Kenyon, A. S. (2012). Technology-Enhanced Assessment of Math Fact Automaticity: Patterns of Performance for Low- and Typically Achieving Students. *Assessment for Effective Intervention*, *37*(2), 84–94. https://doi.org/10.1177/1534508411430321

Strobach, T., Frensch, P. A., & Schubert, T. (2012). Video game practice optimizes executive control skills in dual-task and task switching situations. *Acta Psychologica*, *140*(1), 13–24. https://doi.org/10.1016/j.actpsy.2012.02.001

Suh, S., Kim, S. W., & Kim, N. J. (2010). Effectiveness of MMORPG-based instruction in elementary English education in Korea. *Journal of Computer Assisted Learning*, *26*(5), 370–378. https://doi.org/10.1111/j.1365-2729.2010.00353.x

Sungur, H., & Boduroglu, A. (2012). Action video game players form more detailed representation of objects. *Acta Psychologica*, *139*(2), 327–334. https://doi.org/10.1016/j.actpsy.2011.12.002

Sutton, R. S. (1992). Introduction: The challenge of reinforcement learning. *Machine Learning*, *8*(3–4), 225–227. https://doi.org/10.1007/BF00992695

Sutton, R. S., & Barto, A. G. (1998). *Reinforcement learning: An introduction*. MIT Press.

Sward, K. A., Richardson, S., Kendrick, J., & Maloney, C. (2008). Use of a Web-Based Game to Teach Pediatric Content to Medical Students. *Ambulatory Pediatrics*, *8*(6), 354–359.

Takacs, Z. K., & Bus, A. G. (2016). Benefits of Motion in Animated Storybooks for Children's Visual Attention and Story Comprehension. An Eye-Tracking Study. *Frontiers in Psychology*, *7*. https://doi.org/10.3389/fpsyg.2016.01591

Tamborini, R., & Skalski, P. (2012). The role of presence in the experience of electronic games. In P. Vorderer & J. Bryant (Eds.), *Playing Video Games: Motives, Responses, and Consequences.* (pp. 225–240). Taylor and Francis. http://public.eblib.com/choice/publicfullrecord.aspx?p=446619

Thiede, K. W. (1996). The Relative Importance of Anticipated Test Format and Anticipated Test Difficulty on Performance. *The Quarterly Journal of Experimental Psychology Section A*, *49*(4), 901–918. https://doi.org/10.1080/713755673

Tombu, M., & Seiffert, A. E. (2008). Attentional costs in multiple-object tracking. *Cognition*, *108*(1), 1–25. https://doi.org/10.1016/j.cognition.2007.12.014

Tommerdahl, J. (2010). A model for bridging the gap between neuroscience and education. *Oxford Review of Education*, *36*(1), 97–109. https://doi.org/10.1080/03054980903518936

Toups, Z. O., Kerne, A., & Hamilton, W. (2009). *Motivating play through score*. ACM Computer Human Interaction 2009 Workshop on Engagement by Design, Massachusetts, USA.

Townsend, J. T., & Ashby, F. G. (1978). Methods of modeling capacity in simple processing systems. In J. Castellan & F. Restle (Eds.), *Cognitive Theory: Vol. Vol. 3* (pp. 200–239). Erlbaum.

Treisman, A. (1996). The binding problem. *Current Opinion in Neurobiology*, *6*(2), 171–178.

Trick, L. M., Jaspers-Fayer, F., & Sethi, N. (2005). Multiple-object tracking in children: The "Catch the Spies" task. *Cognitive Development*, *20*(3), 373–387. https://doi.org/10.1016/j.cogdev.2005.05.009

Trick, L. M., Perl, T., & Sethi, N. (2005). Age-Related Differences in Multiple-Object Tracking. *The Journals of Gerontology: Series B*, *60*(2), P102–P105. https://doi.org/10.1093/geronb/60.2.P102

Tulving, E. (2002). Episodic Memory: From Mind to Brain. *Annual Review of Psychology*, *53*(1), 1–25. https://doi.org/10.1146/annurev.psych.53.100901.135114

Turner, D. A. (2011). Which part of ‘two way street’ did you not understand? Redressing the balance of neuroscience and education. *Educational Research Review*, *6*(3), 223–231. https://doi.org/10.1016/j.edurev.2011.10.002

Unsworth, N., Redick, T. S., McMillan, B. D., Hambrick, D. Z., Kane, M. J., & Engle, R. W. (2015). Is Playing Video Games Related to Cognitive Abilities? *Psychological Science*, *26*(6), 759–774. https://doi.org/10.1177/0956797615570367

van der Meulen, A., Krabbendam, L., & de Ruyter, D. (2015). Educational Neuroscience: Its Position, Aims and Expectations. *British Journal of Educational Studies*, *63*(2), 229–243. https://doi.org/10.1080/00071005.2015.1036836

Van der Stigchel, S., & Olivers, C. N. L. (2019). The Flexible Nature of the Interaction Between Attention and Working Memory. *Journal of Cognition*, *2*(1), 1–3. https://doi.org/10.5334/joc.68

Van der Zee, E. A., Platt, B., & Riedel, G. (2011). Acetylcholine: Future research and perspectives. *Behavioural Brain Research*, *221*(2), 583–586. https://doi.org/10.1016/j.bbr.2011.01.050

Vandercruysse, S., Vandewaetere, M., Cornillie, F., & Clarebout, G. (2013). Competition and students’ perceptions in a game-based language learning environment. *Educational Technology Research and Development*, *61*(6), 927–950. https://doi.org/10.1007/s11423-013-9314-5

Vandierendonck, A. (2017). A comparison of methods to combine speed and accuracy measures of performance: A rejoinder on the binning procedure. *Behavior Research Methods*, *49*(2), 653–673. https://doi.org/10.3758/s13428-016-0721-5

Vandierendonck, A. (2018). Further Tests of the Utility of Integrated Speed-Accuracy Measures in Task Switching. *Journal of Cognition*, *1*(1). https://doi.org/10.5334/joc.6

Varma, S., McCandliss, B. D., & Schwartz, D. L. (2008). Scientific and Pragmatic Challenges for Bridging Education and Neuroscience. *Educational Researcher*, *37*(3), 140–152.

Voermans, N. C., Petersson, K. M., Daudey, L., Weber, B., van Spaendonck, K. P., Kremer, H. P. H., & Fernández, G. (2004). Interaction between the Human Hippocampus and the Caudate Nucleus during Route Recognition. *Neuron*, *43*(3), 427–435. https://doi.org/10.1016/j.neuron.2004.07.009

Vogel, J. J., Vogel, D. S., Cannon-Bowers, J., Bowers, C. A., Muse, K., & Wright, M. (2006). COMPUTER GAMING AND INTERACTIVE SIMULATIONS FOR LEARNING: A META-ANALYSIS. *Journal of Educational Computing Research*, *34*(3), 229–243. https://doi.org/10.2190/FLHV-K4WA-WPVQ-H0YM

Vonk, J., & Beran, M. J. (2012). Bears ‘Count’ Too: Quantity Estimation and Comparison in Black Bears (Ursus Americanus). *Animal Behaviour*, *84*(1), 231–238. https://doi.org/10.1016/j.anbehav.2012.05.001

Vorderer, P., Hartmann, T., & Klimmt, C. (2003). Explaining the enjoyment of playing video games: The role of competition. *Proceedings of the Second International Conference on Entertainment Computing*, 1–9.

Voss, J. F. (1974). Acquisition and nonspecific transfer effects in prose learning as a function of question form. *Journal of Educational Psychology*, *66*(5), 736–740. https://doi.org/10.1037/h0037490

Weber, R., Behr, K.-M., & DeMartino, C. (2014). Measuring Interactivity in Video Games. *Communication Methods and Measures*, *8*(2), 79–115. https://doi.org/10.1080/19312458.2013.873778

Wei, L., Zhang, X., Li, Z., & Liu, J. (2018). The semantic category-based grouping in the Multiple Identity Tracking task. *Attention, Perception, & Psychophysics*, *80*(1), 118–133. https://doi.org/10.3758/s13414-017-1420-8

Wei, L., Zhang, X., Lyu, C., Hu, S., & Li, Z. (2017). Brain activation of semantic category-based grouping in multiple identity tracking task. *PLOS ONE*, *12*(5), e0177709. https://doi.org/10.1371/journal.pone.0177709

Wei, L., Zhang, X., Lyu, C., & Li, Z. (2016). The Categorical Distinction Between Targets and Distractors Facilitates Tracking in Multiple Identity Tracking Task. *Frontiers in Psychology*, *7*. https://doi.org/10.3389/fpsyg.2016.00589

West, G. L., Drisdelle, B. L., Konishi, K., Jackson, J., Jolicoeur, P., & Bohbot, V. D. (2015). Habitual action video game playing is associated with caudate nucleus-dependent navigational strategies. *Proc. R. Soc. B*, *282*(1808), 20142952. https://doi.org/10.1098/rspb.2014.2952

West, G. L., Stevens, S. A., Pun, C., & Pratt, J. (2008). Visuospatial experience modulates attentional capture: Evidence from action video game players. *Journal of Vision*, *8*(16), 13–13. https://doi.org/10.1167/8.16.13

Westwood, P. S. (2013). *Numeracy and learning difficulties: Approaches to teaching and assessment*. David Fulton Publishers.

Wheeler, M. E., & Treisman, A. M. (2002). Binding in short-term visual memory. *Journal of Experimental Psychology: General*, *131*(1), 48–64. https://doi.org/10.1037/0096-3445.131.1.48

Wiedermann, W., & von Eye, A. (2013). Robustness and power of the parametric t test and the nonparametric Wilcoxon test under non-independence of observations. *Psychological Test and Assessment Modeling*, *55*(1), 39–61.

Wolpert, D. M., Diedrichsen, J., & Flanagan, J. R. (2011). Principles of sensorimotor learning. *Nature Reviews Neuroscience*, *12*(12), 739–751.

Woltz, D. J., & Was, C. A. (2006). Availability of related long-term memory during and after attention focus in working memory. *Memory & Cognition*, *34*(3), 668–684. https://doi.org/10.3758/BF03193587

Wouters, P., van Nimwegen, C., van Oostendorp, H., & van der Spek, E. D. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology*, *105*(2), 249–265. https://doi.org/10.1037/a0031311

Yu, F.-Y. (2003). The mediating effects of anonymity and proximity in an online synchronized competitive learning environment. *Journal of Educational Computing Research*, *29*(2), 153–167.

Zazkis, R. (2005). Representing numbers: Prime and irrational. *International Journal of Mathematical Education in Science and Technology*, *36*(2–3), 207–217. https://doi.org/10.1080/00207390412331316951

Zazkis, R., & Campbell, S. (1996). Prime decomposition: Understanding uniqueness. *The Journal of Mathematical Behavior*, *15*(2), 207–218. https://doi.org/10.1016/S0732-3123(96)90017-6

Zazkis, R., & Liljedahl, P. (2004). Understanding Primes: The Role of Representation. *Journal for Research in Mathematics Education*, *35*(3), 164–186. https://doi.org/10.2307/30034911

Zhao, L., Gao, Q., Ye, Y., Zhou, J., Shui, R., & Shen, M. (2014). The Role of Spatial Configuration in Multiple Identity Tracking. *PLOS ONE*, *9*(4), e93835. https://doi.org/10.1371/journal.pone.0093835

Appendix I. Information sheet

University of BRISTOL

Information Sheet

Project: The action in learning

You are invited to take part in a voluntary study to explore the relationship between computer games and learning. Therefore, the main task will be to play with a computer game for learning.

The session will take place at the School of Education. During the session, you will be first asked to complete a pre-test on the content of the game using a computer-based application. Then, you will have the chance to play the game according to the instructions provided. At the end of the session, you will be asked to complete a post-test (like the pre-tests) to see how much you have learned while playing.

The data collected will be analysed in order to obtain information about the influence of action in learning. All published data will be treated anonymously, i.e. it will be not linked to any other information that may reveal your identity. However, you will be asked to provide your date of birth and sex for data analysis purposes. You will also be asked to provide a one-word pseudonym to identify your results and your email to contact you.

You do not need to be an avid video game player to participate.

All testing will take place in a room at the School of Education, University of Bristol. Your participation is voluntary but highly appreciated. About data collected, you will have the right to ask for its withdrawal until one week after completing participation. Likewise, you will have the right to withdraw from the study at any point without the need of providing reasons for it.

Should you have any further inquiries related to this study, please do not hesitate to contact the researcher.

Carolina Gordillo: carolina.gordillo@bristol.ac.uk (Researcher) or the principal supervisor: Paul Howard-Jones, paul.howard-jones@bristol.ac.uk.

In case of any complaints related to the procedures employed in this research, these will need to be directed to the principal supervisor (email above).

I very much appreciate the time you will take to contribute to my research.

Appendix II. Informed consent

University of BRISTOL

Informed Consent Form

Project: the action in learning

Please read and tick the boxes as confirmation of your understanding:

☐ I understand that my participation in this project will involve taking part in an experiment using a computer game in which data about my performance will be collected by the computer.

☐ I understand that participation in this study is completely voluntary and that I can withdraw from the study at any time without the need to provide further explanation.

☐ I understand that the information provided by me will be treated confidentially, such that only the researcher can track this information back to me individually, and that individual performance in the experiment will be made public using a pseudonym of my choosing.

☐ I understand that I am free to ask any questions at any time and to discuss my concerns with the researcher and/or research supervisor
(**Researcher**: Carolina Gordillo: carolina.gordillo@bristol.ac.uk **Supervisor**: Paul Howard-Jones: paul.howard-jones@bristol.ac.uk)

☐ The information will be retained for further studies and publication. I understand that I can ask for the information I provide to be deleted/destroyed up to a week after my participation.

☐ I also understand that at the end of the study I will be provided with additional information and feedback about the purpose of the study and its findings.

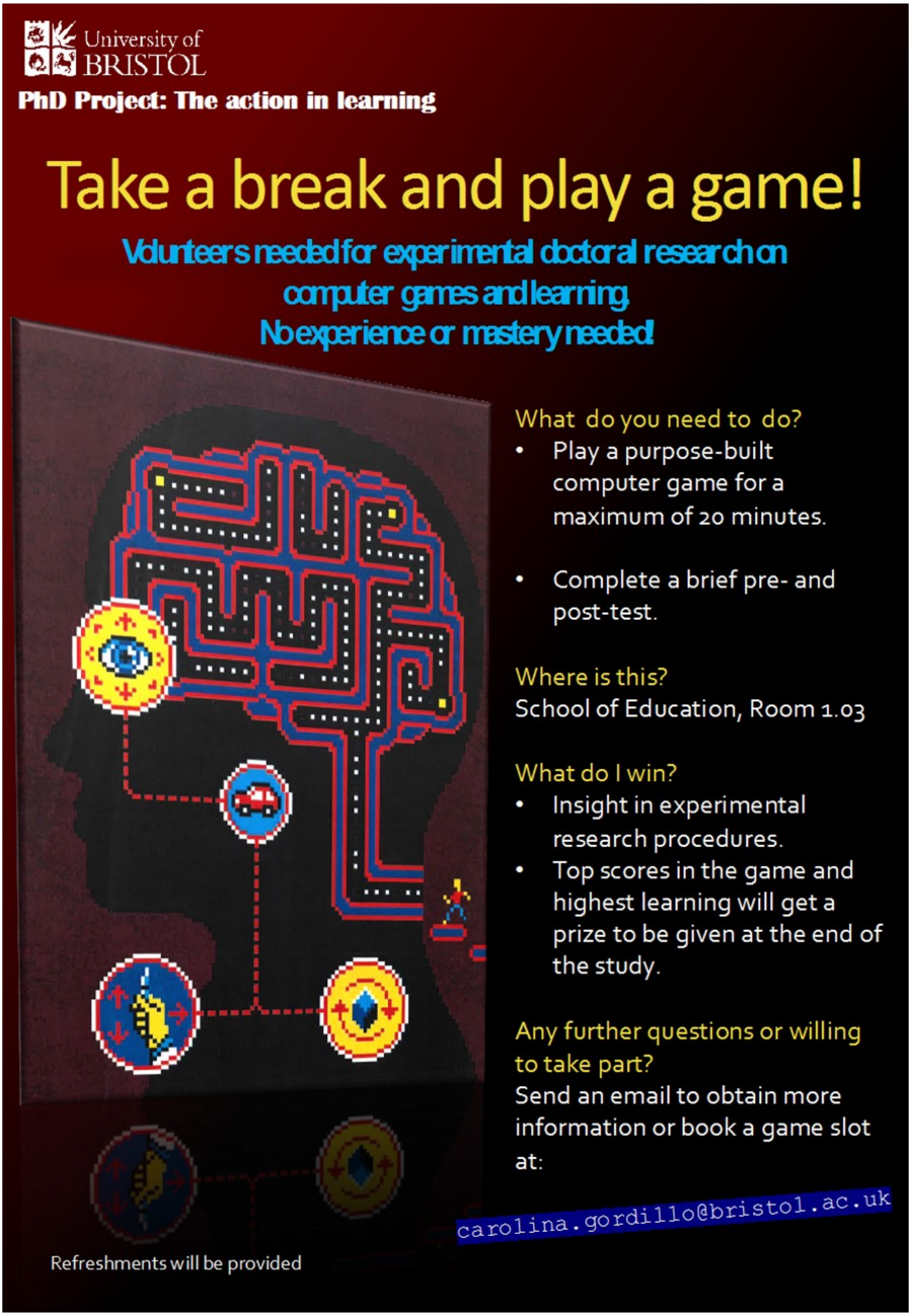
☐ I have understood all the above mentioned information.

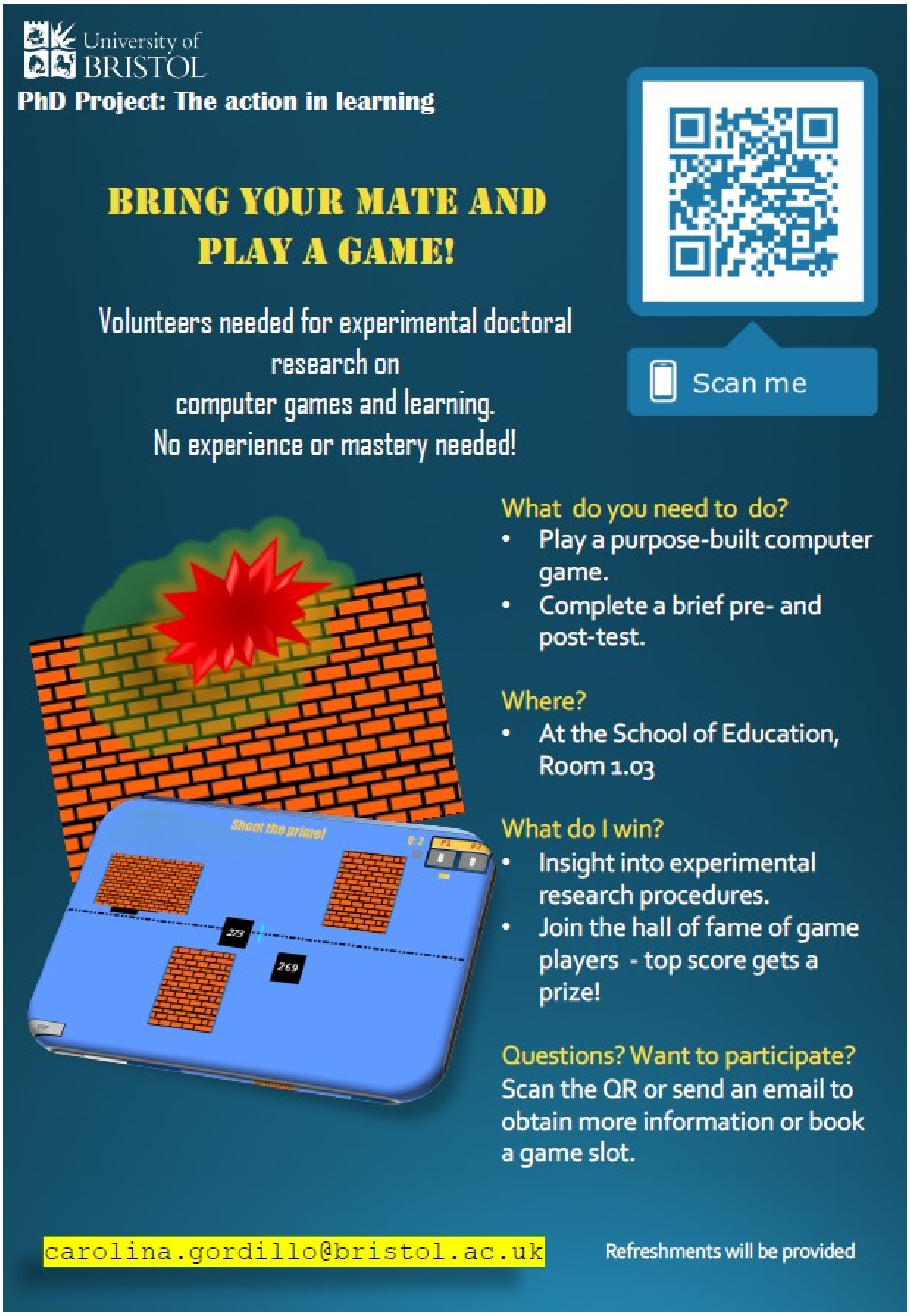
I, ___________________________________ (YOUR NAME) consent to participate in the study conducted by Carolina Gordillo at Graduate School of Education, University of Bristol.

Signed: ______________________________

CONTACT DETAILS
Date of Birth (DD/MM/YY): _____________________________ **Sex:** ____________
E-mail address: ____
Pseudonym: __________________

Appendix III. Posters for participant recruitment


University of BRISTOL
PhD Project: The action in learning
Take a break and play a game!
Volunteers needed for experimental doctoral research on computer games and learning
No experience or mastery needed!
What do you need to do?
• Play a purpose-built computer game for a maximum of 20 minutes.
• Complete a brief pre- and post-test.
Where is this?
School of Education, Room 1.03
What do I win?
• Insight in experimental research procedures.
• Top scores in the game and highest learning will get a prize to be given at the end of the study.
Any further questions or willing to take part?
Send an email to obtain more information or book a game slot at:
carolina.gordillo@bristol.ac.uk
Refreshments will be provided


University of BRISTOL
PhD Project: The action in learning
BRING YOUR MATE AND PLAY A GAME!
Volunteers needed for experimental doctoral research on
computer games and learning.
No experience or mastery needed!
Scan me
What do you need to do?
Play a purpose-built computer game.
Complete a brief pre- and post-test.
Where?
At the School of Education, Room 1.03
What do I win?
Insight into experimental research procedures.
Join the hall of fame of game players - top score gets a prize!
Questions? Want to participate?
Scan the QR or send an email to obtain more information or book a game slot.
Shoot the prime!
carolina.gordillo@bristol.ac.uk
Refreshments will be provided

Appendix IV. Instructions for participants

Game-like task 1 in Experiments 1 and 2

University of BRISTOL

Read-aloud instructions

In this experiment, you will be asked to play a computer game in which you will have to guess the prime numbers.

A prime number is one that can be divided evenly by itself and by 1 only.

You will be pre tested on these numbers before playing the first game. This pre-test consists of ____ [*number*] questions. On the screen, you will see four numbers under the *question Which is the prime number?* Whenever you identify a prime number, click on the correct symbol on the keyboard [*show symbols on keyboard*]. There is a time bar on the right side of the screen indicating how much time you have left to respond.

Once the pre-test is completed, you will play the first game according to the distribution list.

Once you have played the two games, you will perform a post-test to see how much you have learned.

[*Conduct pre-test*]

Now you are going to play the games

[Read before starting each game according to the distribution list]

Motion game:

In this game you will need to use the mouse. There are 15 questions in each game. You will see a box with numbers that change and move around the screen. Click on the number you think is a prime to obtain points.

Once finished, you will play a second game with a variation in the conditions.

[Read before the second condition begins]

Static game:

In this game you will need to use the mouse. There are 15 questions in each game. You will see a box with numbers that change. Click on the number you think is a prime to obtain points.

Game-like task 2 in Experiment 3

Read-aloud instructions

In this experiment, you will be asked to play a computer game in which you will have to guess the prime numbers.

A prime number is one that can be divided evenly by itself and by 1 only.

You will be pretested on these numbers before playing the game. This pretest consists of 40 questions. [*Showing the handout*] In the screen you will see four numbers under the *question Which is the prime number?* Whenever you identify a prime number, click on the correct symbol on the keyboard [*show symbols*]. There is a bar time on the right side of the screen indicating how much time you have left to complete the test.

Once the pretest is completed, you will start playing the game. Once the game is finished, you will perform a post-test to see how much you have learned.

Do you have any questions? [If not, then proceed with the tester or answer questions]

[*Instructions for the game*]

In the game, you will see a screen divided by a central line with an aim in the centre. Four numbers will appear on the screen. Only one of them is a prime number. There are two types of trials in this game: motion and static and they will appear in an alternate fashion.

Motion trials: *[Use sequence of screenshots to explain, next page]*

In the motion trials, numbers will move around the screen, when you have identified your prime number, wait until it crosses the line and move the aim using the right-hand clickers. When the number is in the centre of the aim you click to fire at the number with the left-hand clicker.

Static trials: *[Use sequence of images to explain, next page]*

Numbers will appear in the four quadrants of the screen. When you have identified your prime number, move the aim (left of right) using the right-hand clicker and once in the place click the up or down button using the left-hand clicker.

You will receive feedback after every trial and you can use it in subsequent trials. If your response is correct, you will earn 10 points. Your score will be shown on the top-right corner of the screen.

Do you have any questions? [*If not, then proceed with the game or answer questions*]

We will have some time for practice. This score will not count towards your final score. It is just for you to get used to play with the controls. [Set up a practice test with 5 trials using a different corpus]

[*Once trial is finished]* Do you need another practice?

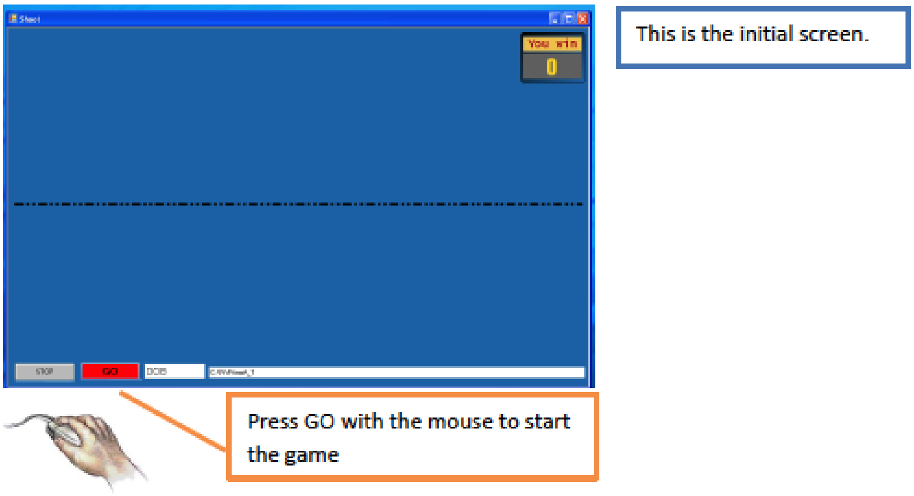
[*Once the game is finished, write down the score on the board next to the participant's chosen pseudonym*]

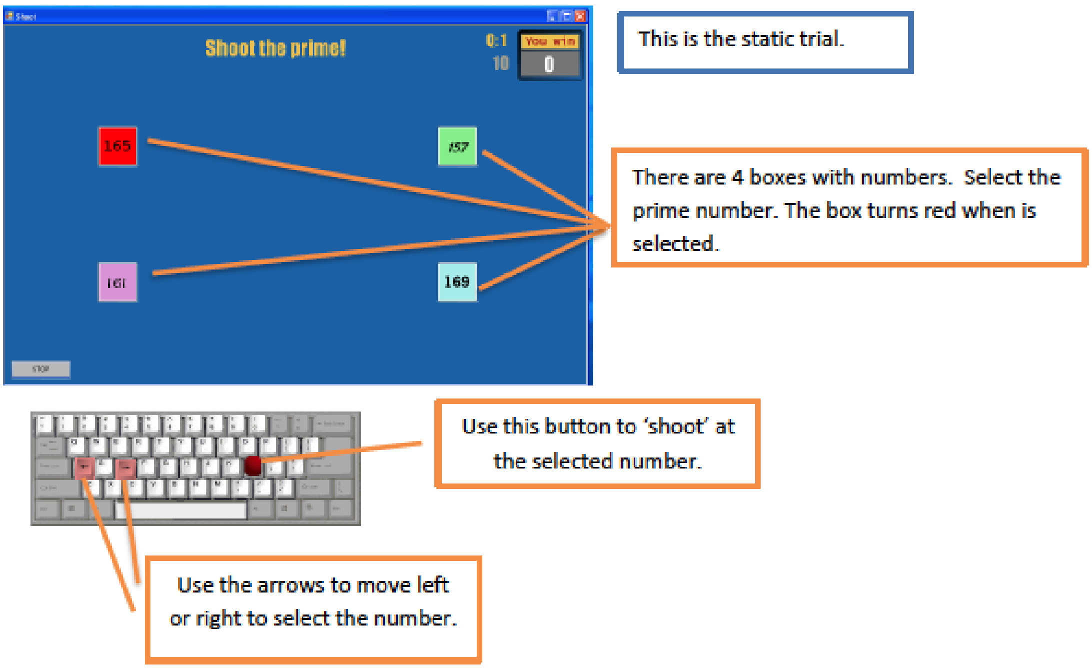
How did you feel playing the game? [*After an answer, prompt the participant to the next step, the posttest*]

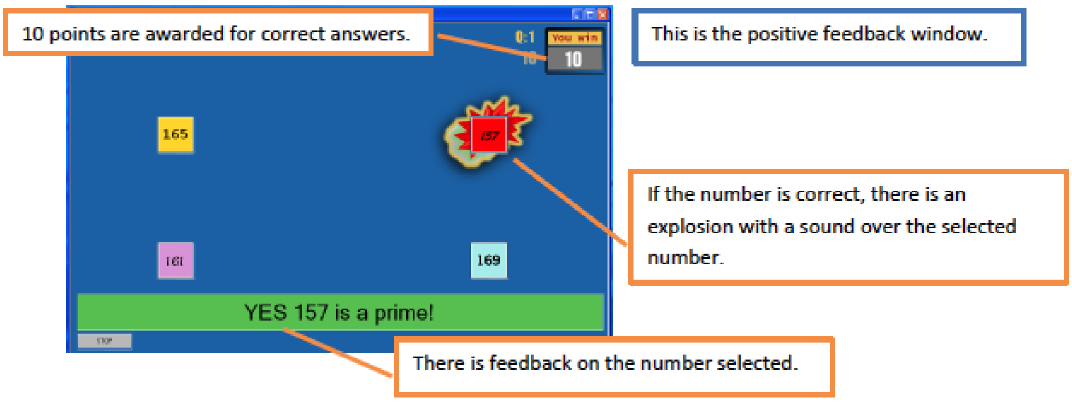
And finally, you will perform a posttest, which is exactly like the first test you took at the beginning to see how much you have learned from the game. Are you ready? [*Start the posttest if not questions arise*].

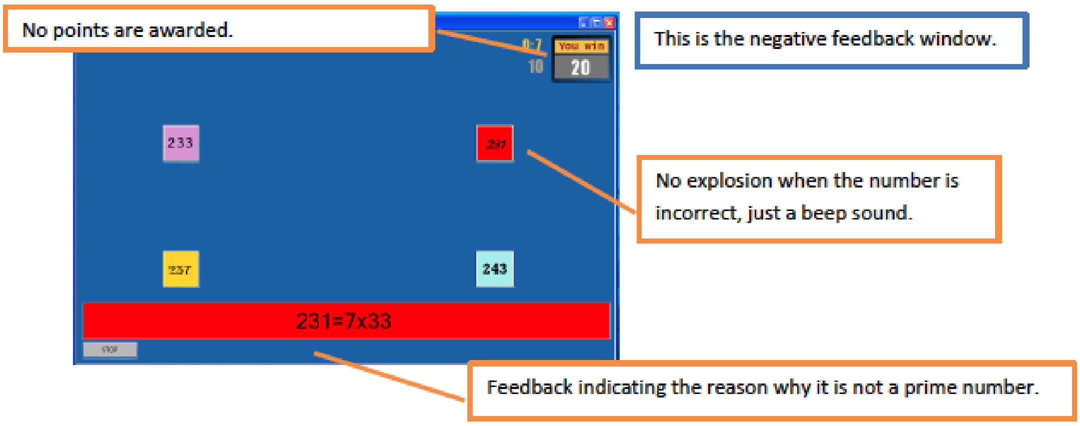
[Thank the participant and explain that the score obtained in this stage of pre and posttest cannot yet be informed but that results will be emailed later once the experiment had finished.

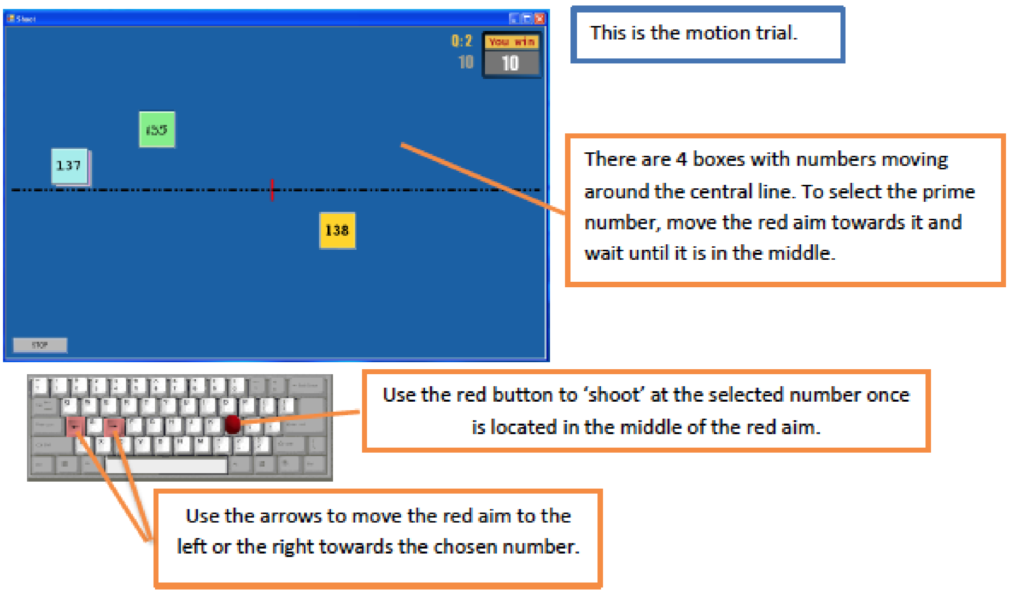
Shoot Game – Explained

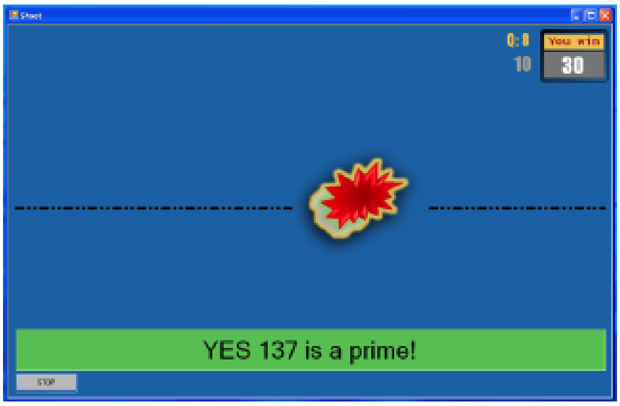




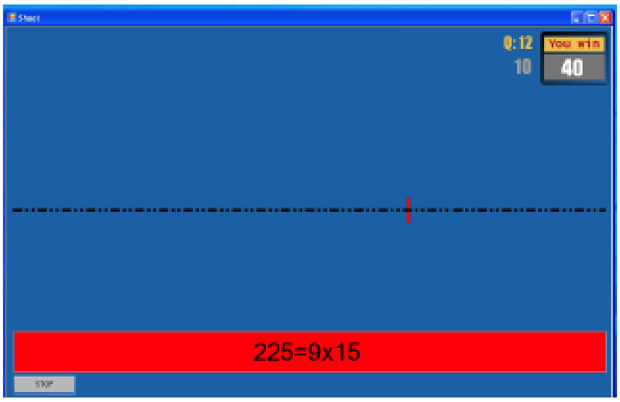

10 points are awarded for correct answers.
This is the positive feedback window.
You win
10
165
157
161
169
If the number is correct, there is an explosion with a sound over the selected number.
YES 157 is a prime!
There is feedback on the number selected.


No points are awarded.
This is the negative feedback window.
You win
20
233
231
237
243
No explosion when the number is incorrect, just a beep sound.
231=7x33
Feedback indicating the reason why it is not a prime number.

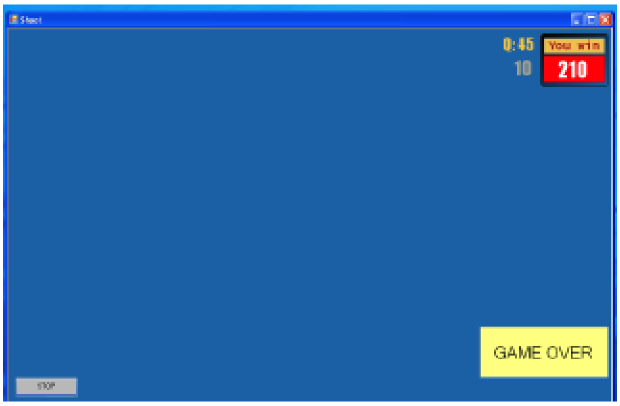

This is the motion trial.
You win
10
155
137
138
There are 4 boxes with numbers moving around the central line. To select the prime number, move the red aim towards it and wait until it is in the middle.
Use the red button to 'shoot' at the selected number once is located in the middle of the red aim.
Use the arrows to move the red aim to the left or the right towards the chosen number.



This is the positive feedback window.

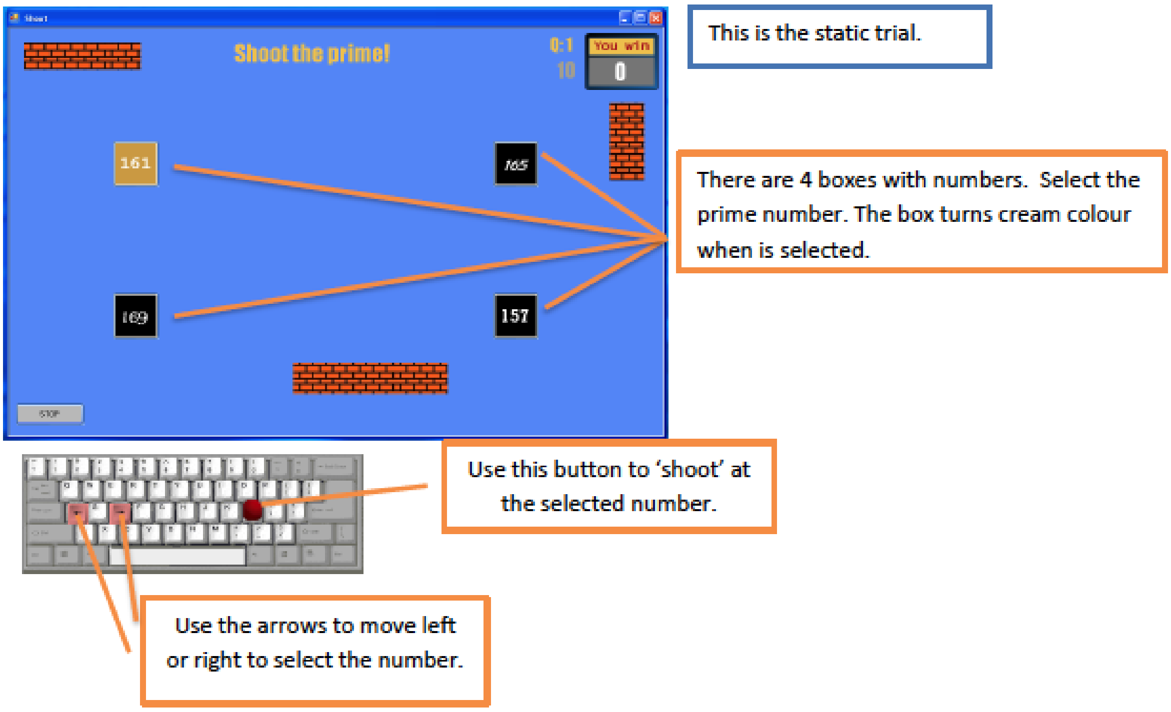


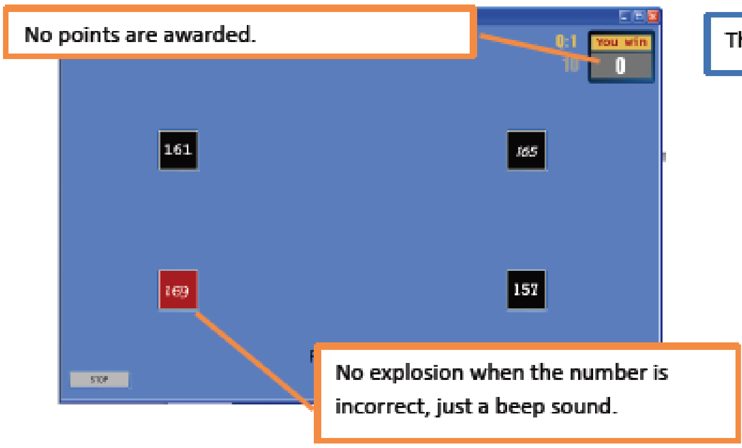
This is the negative feedback window.

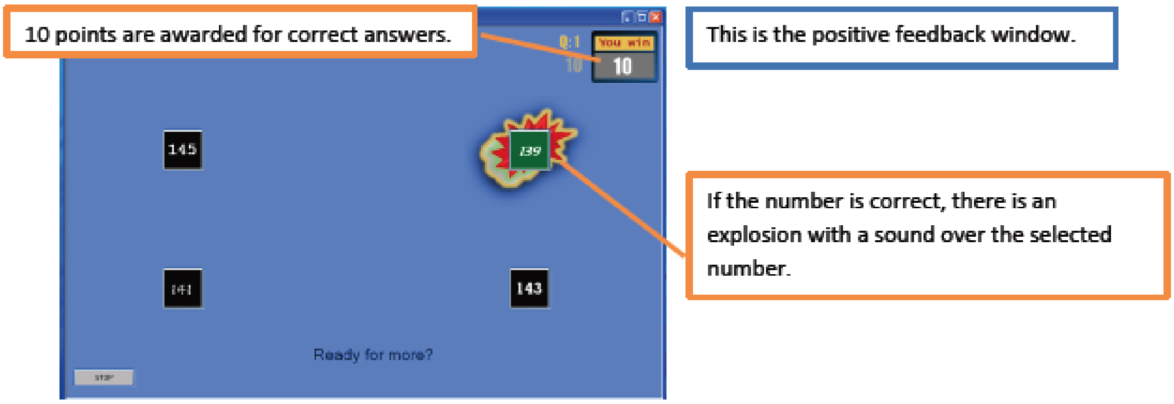


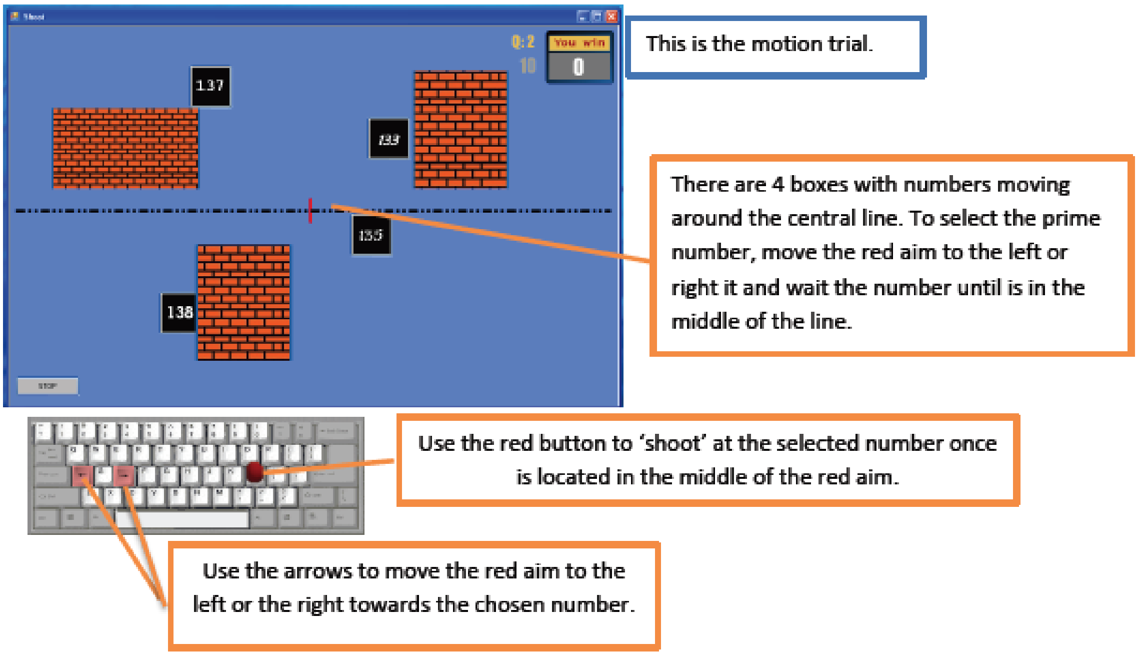
GAME OVER window after 45 alternate trials.

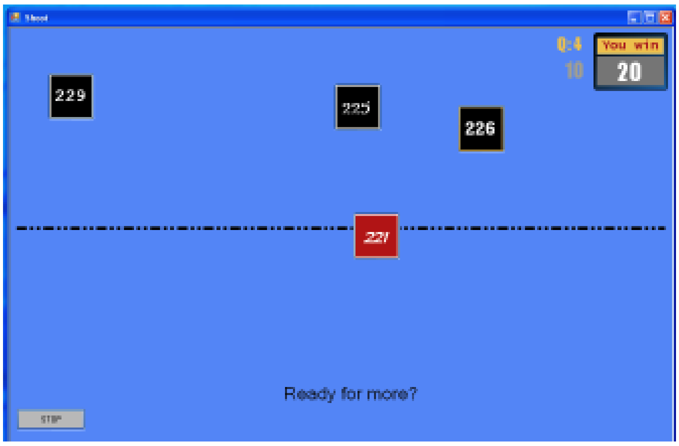
Game-like task 2 in Experiment 4




No points are awarded.
You win
0
161
165
169
157
No explosion when the number is incorrect, just a beep sound.
This is the negative feedback window.


10 points are awarded for correct answers.
You win
10
145
139
141
143
Ready for more?
This is the positive feedback window.
If the number is correct, there is an explosion with a sound over the selected number.


You win
0
137
133
155
138
This is the motion trial.
There are 4 boxes with numbers moving around the central line. To select the prime number, move the red aim to the left or right it and wait the number until is in the middle of the line.
Use the red button to 'shoot' at the selected number once is located in the middle of the red aim.
Use the arrows to move the red aim to the left or the right towards the chosen number.



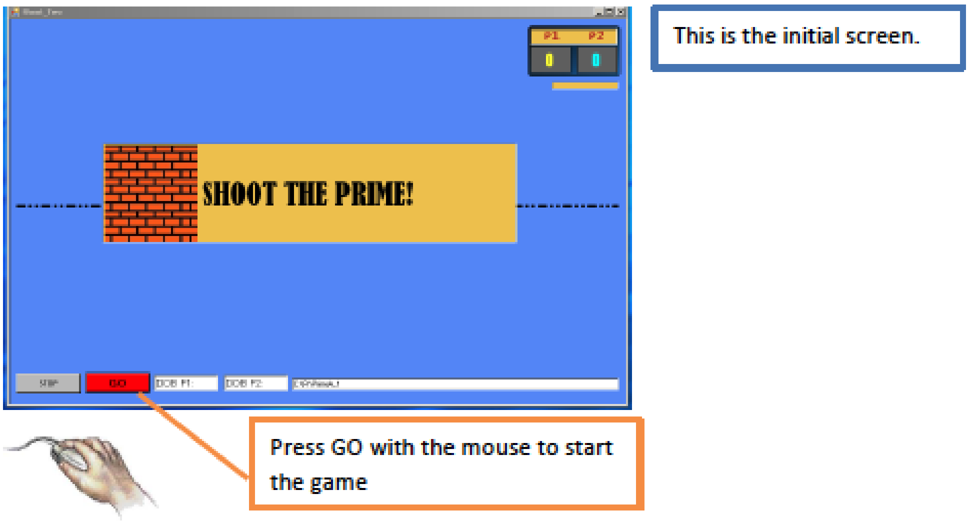
This is the negative feedback window.

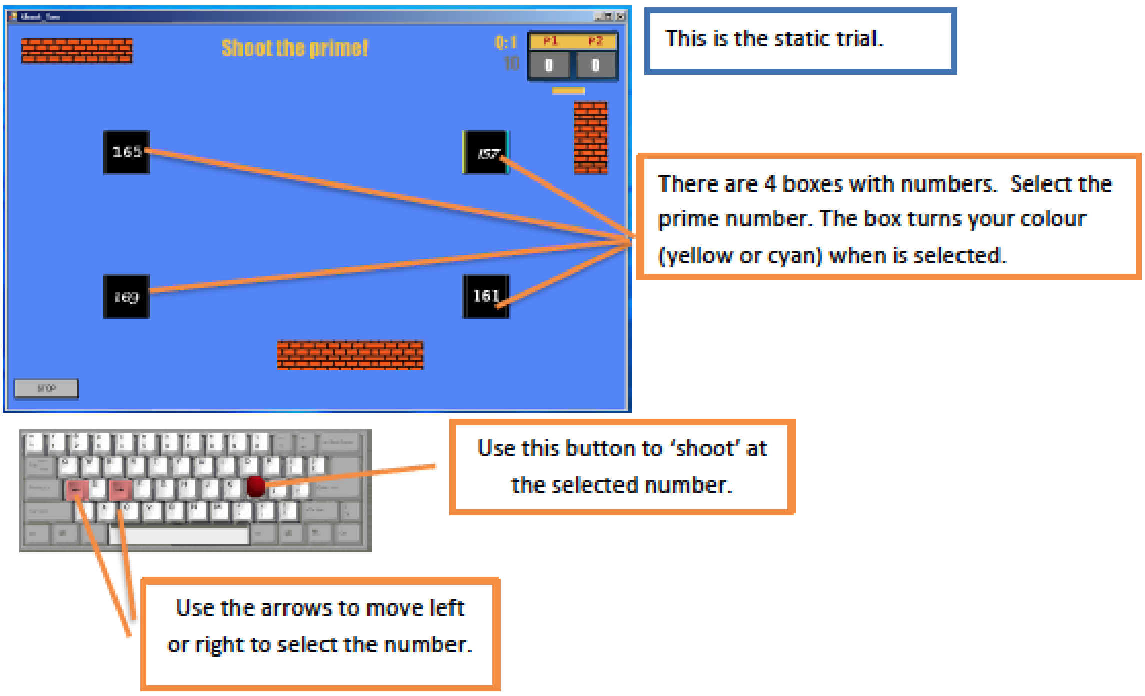
This is the positive feedback window.

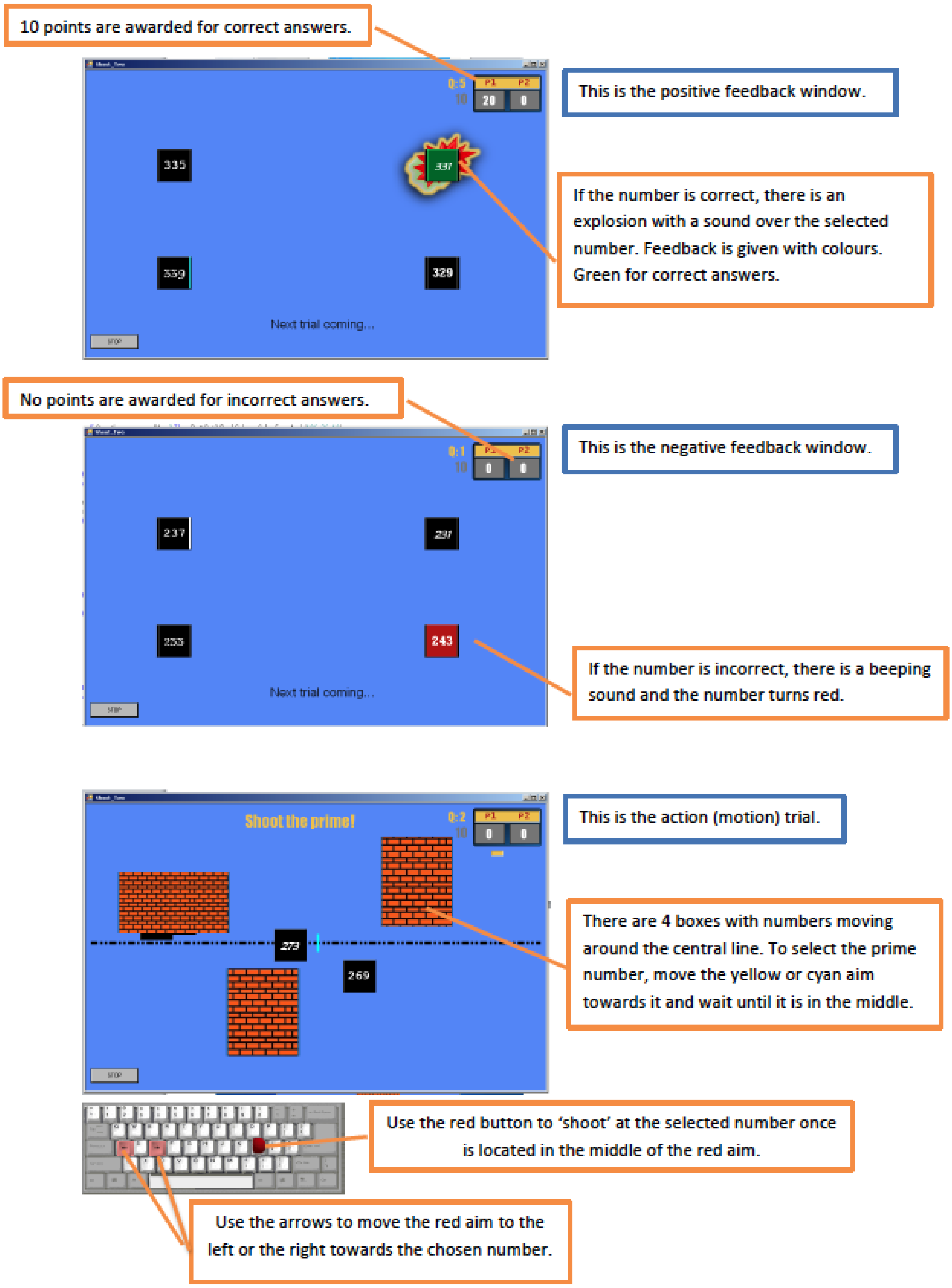
This is the end of the game.

Game-like task 2 (2P-mode) in Experiment 5

Shoot 2P






10 points are awarded for correct answers.
This is the positive feedback window.
335
337
339
329
Next trial coming...
If the number is correct, there is an explosion with a sound over the selected number. Feedback is given with colours. Green for correct answers.
No points are awarded for incorrect answers.
This is the negative feedback window.
237
237
255
243
Next trial coming...
If the number is incorrect, there is a beeping sound and the number turns red.
This is the action (motion) trial.
Shoot the prime!
273
269
There are 4 boxes with numbers moving around the central line. To select the prime number, move the yellow or cyan aim towards it and wait until it is in the middle.
Use the red button to 'shoot' at the selected number once is located in the middle of the red aim.
Use the arrows to move the red aim to the left or the right towards the chosen number.

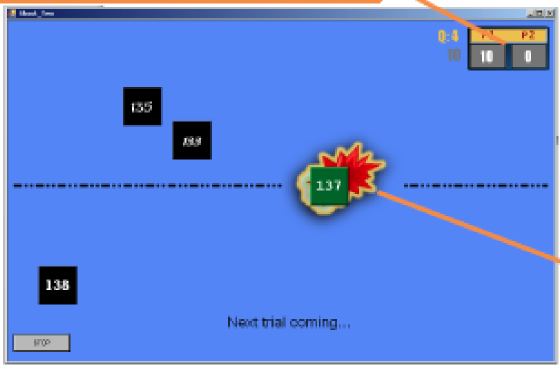
No points are awarded for incorrect answers.

This is the negative feedback window.

If the number is incorrect, there is a beeping sound and the number turns red.

10 points are awarded for correct answers.

This is the positive feedback window.



If the number is correct, there is an explosion with a sound over the selected number. Feedback is given with colours. Green for correct answers.

GAME OVER window after 100 alternate trials.

Appendix V. Ethics approval summary

Ethical issues discussed and decisions taken (see list of prompts overleaf):

Researcher access/exit

A request for participation will be advertised to University of Bristol students within university facilities and via email. Interested participants will then need to contact the researcher for further details of the participation.

More participants will be contacted via snowballing technique by asking those participants already involved in the research to invite other colleagues or classmates to take part of the project. In order to maintain an equal degree of participation in the tasks, this contact needs to be made before the onset of the experiment.

The ending point of physical participation will be the email with their general results.

Participants will not receive monetary payment for their participation, but complimentary food and refreshments will be offered.

Information sheet and informed consent

Participants will be informed at all times of the procedures they will undergo in the study. They will receive an information sheet with a general description of the experiment. However, they will remain unaware of the content of the tasks (prime numbers) to avoid preparation.

Participant's informed consent will be requested. This will explain the tasks, the time involved, the personal details they will need to provide as well as the confidentiality and anonymity treatment of such information. Also, their right of withdrawal at any stage of the research will be emphasized in this document (see Informed consent)

Complaints procedure

The information sheet will establish that participants can present any complaints about the procedures involved in this project to the PhD supervisor via email.

Safety and well-being of participants/ researchers

There are no physical or psychological harms associated with this experiment to either participants or the researcher.

Anonymity/ confidentiality

There are documents in the process of obtaining consent that will inevitably contain personal details of participants. In order to comply with confidentiality issues, physical documents will be kept secured in a University office cabinet. To keep anonymity standards, participants will be identified with a coded-information ID which is only accessible to members of the research team using that information.

Computer tasks will only register the participant's date of birth together with their results in accuracy of responses and RT.

Data collection, analysis and storage

All physical paperwork containing personal details of participants will be secured in the laboratory office. Once research has concluded, they will be destroyed.

Behavioural data will be recorded under participants' date of birth in the computer where the tasks are installed via text editor. This is a computer located in a purpose-allocated laboratory at the Graduate School of Education. Data will be transferred to an Excel spreadsheet after each data collection session. Files will be stored in the University server. Data will be used for the intended research purposes and will be kept for further analysis once the research has concluded.

Feedback and reporting of research

While playing the games, participants will receive immediate feedback on their score and also a learning feedback (for correct and incorrect responses). Nevertheless, they will remain unaware of their learning (measured by the testing) until all individuals have finished their participation.

This study will be part of a doctoral thesis and therefore its results will be published in a thesis and journal article.

Responsibilities to colleagues/ academic community

Permanent report and liaison to supervisor will ensure research is conducted thoroughly and under parameters that guarantee the integrity of the general research process, data collection and results reported.

Appendix VI. Summary of pre/posttest difference for accuracy and response time

Experiment	Motion		Static	
	Accuracy	RT	Accuracy	RT
1	+5	-4.44	+13	-3.18
2	+38.15	-4.74	+34.35	-4.41
3	+21.51	-0.99	+16.18	-6.43
4	+17.18	-11.53	+20.13	-7.64
5	+14.86	-4.69	+10.71	-2.34

Appendix VII. Summary of statistical test results

Phase 1

Experiment 1

Stage	Variable	Hypothesis	Results
Testing	Accuracy	H_1	$t(19) = -1.04$, $p = .314$, $d = 0.27$ (Static)
	RT	H_2	$t(19) = -.439$, $p = .665$, $d = 0.14$. (Motion)

Experiment 2

Stage	Variable	Hypothesis	Results
Testing	Accuracy	H_1	$F(2.83, 42.41) = 40.7$, $p < .001$, $\eta^2_{partial} = .73$ (time) $F(1, 15) = 2.34$, $p = .147$, $\eta^2_{partial} = .14$ (condition) $F(5, 75) = .458$, $p = .806$, $\eta^2_{partial} = .030$ (interaction)
	RT	H_2	$F(2.15, 32.3) = 20.1$, $p < .001$, $\eta^2_{partial} =.57$ (time) (Motion) $F(1, 15) = 4.58$, $p = .049$, $\eta^2_{partial} = .23$ (condition) $F(2.6, 39.1) = 2.0$, $p = .139$, $\eta^2_{partial} = .12$ (interaction)

Phase 2

Experiment 3

Stage	Variable	Hypothesis	Results
Testing	Accuracy	H_1	$t(18) = -.835$, $p = .415$, $d = 0.19$ (Motion)
	RT	H_2	$t(18) = 1.04$, $p = .311$, $d = 0.24$. (Static)

Experiment 4

Stage	Variable	Hypothesis	Results
Testing	Accuracy	H_1	$t(48) = -.637$, $p = .527$, $d = 0.09$
	RT	H_2	$t(48) = -1.43$, $p = .154$, $d = 0.20$

Experiment 5

Stage	Variable	Hypothesis	Results
Testing	Accuracy	H_1	$t(50) = 1.40$, $p = .169$, $d = 0.20$
	RT	H_2	$t(50) = -.87$, $p = .386$, $d = 0.12$

Appendix VIII. Power analysis (Post-hoc and sensitivity)

Post-hoc and a sensitivity analyses were conducted using G*Power 3.1. The post-hoc analysis was conducted to understand the power of the study with the possibilities of accessing the sample size used in the experiments. The sensitivity analysis was conducted to determine the effect size that can be expected with higher power (1-ß = 0.95 and 1-ß = 0.80) and the sample size used in each experiment. The following table shows the results for the post-hoc and the sensitivity analyses for each hypotheses tested in the five experiments.

Table 7.1
Power analyses (Post-hoc and Sensitivity)

Experiment	**Hypothesis**	**Post-hoc 1-ß err. probability**	**Sensitivity Effect size (1-ß = 0.80)**	**Sensitivity Effect size (1-ß = 0.95)**
Experiment 1	H_1	0.59	0.42	0.6
	H_2	0.72	0.24	0.45
Experiment 2	H_1	0.37	0.77	1.0
	H_2	0.32	0.49	0.74
Experiment 3	H_1	0.55	0.38	0.57
	H_2	0.53	0.43	0.62
Experiment 4	H_1	0.60	0.20	0.32
	H_2	0.49	0.33	0.44
Experiment 5	H_1	0.52	0.31	0.43
	H_2	0.54	0.24	0.35

Appendix IX. Corpora summary analysis

Corpora 1 & 2	times appeared	% Performance	times appeared	% Performance
Experiment	1		2	
137	235	13.62	523	95.2
151	221	17.65	560	91.43
229	304	9.21	678	66.67
269	324	4.01	737	53.6
337	203	18.72	917	52.02
139	263	11.41	484	81.61
157	237	16.46	532	82.89
233	249	12.85	638	50.78
263	296	9.46	729	54.32
331	222	18.92	902	52.99
M	255.40	13.23	670.0	68.15
SD	40.30	4.85	153.20	17.85

Corpora 3 & 4	times appeared	% Perf.	times appeared	% Perf.	times appeared	% Perf.
Experiment	3		4		5	
131	78	56.41	485	51.13	239	44.35
149	82	28.05	511	28.77	263	20.15
181	95	52.63	510	38.63	294	35.37
193	91	36.26	514	43.58	279	31.9
379	82	29.27	480	47.29	240	25.83
127	94	27.66	515	29.71	286	25.52
163	88	42.05	488	32.17	260	23.46
179	76	53.95	490	35.31	234	25.21
191	80	43.75	487	43.53	243	36.21
373	89	32.58	520	47.31	284	38.38
M	85.5	40.26	500.0	39.74	262.2	30.64
SD	6.77	11.16	15.20	7.97	22.45	7.77

Appendix X. Game-like task 1 Code

```
Option Strict Off
Option Explicit On
'Module InpOut32_Declarations ' ignore this stuff - it's for recording on BIOPAC
'Inp and Out declarations for port I/O using inpout32.dll.
'Public Declare Function Inp Lib "inpout32.dll" Alias "Inp32" (ByVal PortAddress As Short) As Short
'Public Declare Sub Out Lib "inpout32.dll" Alias "Out32" (ByVal PortAddress As Short, ByVal Value
As Short)
'End Module
Public Class Form1
  Inherits System.Windows.Forms.Form
```

```
  Public Function MyTime() As String
    MyTime = Format(Now, "HH:mm:ss:")
  End Function
```

```
  Dim startTime, trialTime, eventTime, totalTime As DateTime
  Dim quest As Integer ' this variable used to step through the questions
  Dim quest_num As Integer ' this is where we are in game - 1 = first question presented, 2 = 2nd
etc
  Dim key, candidate, taken As Integer
  Dim Taking_Answers As Integer ' indicates when answers via keyboard are acceptable
  Dim Question_responded As Integer
  Dim Question_response As Integer
  Dim Player_Turn_Score, Player_Total_Score, Player_Total_Speed, start_of_trial, start_of_option
As Integer
  Dim ans, missed_ans, x_t, y_t As Integer
  Dim numquest, slide As Integer ' this is the total number of questions in the game,questions per
slide, slide number
  Dim cfg_data(200), questions(100, 20) As String
  Dim x_lo_lim, x_hi_lim, y_lo_lim, y_hi_lim, DISP_I, TRAV_I As Integer
  Dim SelectOrder(100), action, loc_x, loc_y, Opt, cor_incor, NAns, PossAns, disp_interval, rpt_q,
block, First_miss As Integer
  Dim strcfg, strquest, strpoints As String
  Dim MyRandom As New Random
  Dim Trajectory(12, 2) As Integer
  Dim X_trajectory, Y_trajectory, Traj As Integer
  Dim WithEvents Player As System.Windows.Forms.TextBox
```

```
  Public Sub form1_loadquest(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles MyBase.Load
    Trajectory(1, 1) = 0
    Trajectory(1, 2) = 5
    Trajectory(2, 1) = 5
    Trajectory(2, 2) = 0
    Trajectory(3, 1) = 3
    Trajectory(3, 2) = 4
    Trajectory(4, 1) = 0
    Trajectory(4, 2) = 5
    Trajectory(5, 1) = 5
    Trajectory(5, 2) = 0
```

```
    Trajectory(6, 1) = 3
    Trajectory(6, 2) = 4
    For n = 7 To 12
      Trajectory(n, 1) = -Trajectory(n - 6, 1)
      Trajectory(n, 2) = -Trajectory(n - 6, 2)
    Next n
    lblMessage.Text = Trajectory(8, 1) & " " & Trajectory(8, 2)
    'cfg file:
    '01:home directory for files
    '02:question file name
    '03:learning content directory name
    '06:data file name
    '07:number of questions (should correspond with size of 02,03 and 05)
    '08:=1 if Active gaming
    '10:ITI_Timer.Interval = time before the ITI = Gaming Feedback Time
    '11:Start_Trial_Timer.Interval = time before Trial starts = ITI ENDS - BIOPAC Digital Ch 1 Event
starts = Learning presented
    '14:Trial_Timer.Interval = time before trial ends
    '20:number of correct answers
    '21:number of times to repeat questions
    '22:Option Interval
    '23:Travel Interval
```

All about where answer options float on the screen

```
    disp_interval = 2000
    Trav1.Interval = 65
    x_lo_lim = 15
    x_hi_lim = 416
    y_lo_lim = 170
    y_hi_lim = 450
    ActionBox.Location = New Point(x_lo_lim, y_lo_lim)
    ActionBox.Width = x_hi_lim - x_lo_lim + 68 ' 68 is width of box
    ActionBox.Height = y_hi_lim - y_lo_lim + 38 ' 38 is height of box
  End Sub
```

Randomises question order

```
  Public Sub ArrangeQuestionOrder()
    ' SelectOrder will contain the randomised order of questions presented
    For Me.block = 1 To rpt_q
      SelectOrder(1 + (block - 1) * numquest) = MyRandom.Next(numquest) + 1
      For N = 2 To numquest
        candidate = MyRandom.Next(numquest) + 1
        taken = 0
        For SO = 1 To N - 1
          If SelectOrder(SO + (block - 1) * numquest) = candidate Then taken = 1
        Next
        If taken = 0 Then
          SelectOrder(N + (block - 1) * numquest) = candidate
        Else : N = N - 1
        End If
      Next
    Next
    numquest = numquest * rpt_q
  End Sub
```

Starts game after clicking button GO

```
  Public Sub btnNew_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
btnNew.Click
        Dim cfgfile As New System.IO.StreamReader(cfgbox.Text + ".txt")
        Dim lengt, cfg As Integer
        lblMessage.Text = CStr(disp_interval) & "   " & CStr(Trav1.Interval)
        btnNew.BackColor = Color.WhiteSmoke
        quest = 0
        ' lblMessage.Visible = False
        strcfg = cfgfile.ReadLine()
        Do Until strcfg Is Nothing
            For cfg = 1 To 25 ' 21 because that takes strcfg to nothing
                cfg_data(cfg) = strcfg
                strcfg = cfgfile.ReadLine()
                lengt = Microsoft.VisualBasic.Len(cfg_data(cfg))
                If lengt > 3 Then cfg_data(cfg) = Microsoft.VisualBasic.Right(cfg_data(cfg), lengt - 3)
            Next
        Loop
        cfgfile.Close()
        cfgfile.Dispose()
        numquest = cfg_data(7)
        action = cfg_data(8) 'do question move?
        ITI_Timer.Interval = Int(cfg_data(10)) 'Inter-trial interval
        Start_Trial_Timer.Interval = cfg_data(11) ' Time for learning before question - that's zero in
your study?
        Trial_Timer.Interval = cfg_data(14) ' how long the question lasts for
        NAns = cfg_data(20) ' number of times that the correct answer appears
        rpt_q = cfg_data(21) ' number of times that question gets repeated
        DISP_I = cfg_data(22) 'increment by which duration of the display of option is being
increased/decreased - decides how rapidly options are appearing/disappearing
        TRAV_I = cfg_data(23) 'increment by which delay before moving to next position is being
increased/decreased

        If action = 1 Then
            Trav1.Enabled = True 'starts Trav1 is the timer for the answer travelling. Every time it goes
off, the answer moves.
            Selector.Visible = False
        End If
        If action = 0 Then
            Selector.Visible = True
            ButtOpt1.Enabled = False
            ButtOpt2.Enabled = False
            ButtOpt3.Enabled = False
            ButtOpt4.Enabled = False
        End If
        read_questions() ' goes to a routine that loads up the questions into questions(quest, N) where
quest is question number e.g. Q7 and if N = 0, its the question 7, N=1 it's option 1 for question 7 etc
        ArrangeQuestionOrder() ' produces a random sequence of integers (in SelectOrder) from 1 to
NumQuest, for randomising selection of questions
        Taking_Answers = 0 ' this means that its not presently possible to enter an answer
        Player_Total_Score = 0 ' set player score to 0
```

```
        Player_Total_Speed = 0
        Player_score_display.Text = Player_Total_Score ' display the player's score
        Player_Speed_dial.Text = Player_Total_Speed 'display the player's speed based on adaptive
disp_interval
        'Out(&HE050S, &H0S) ' all EVENTs at zero
        ' Below writes an introductory line on data file - includes DOB etc
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), vbNewLine &
"NEW PARTICIPANT" & " " & DOB.Text & " " & cfgbox.Text, True)
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), vbNewLine,
True)
        startTime = Now ' store the start time of the game
        run_game()
    End Sub
```

Starts new trial (after pause set by start trial timer – which is set at a millisecond in the configuration file. Modify to set delay.

```
    Public Sub run_game()
        eventTime = Now ' COLUMN 1 = start of learn
        If quest_num = numquest Then
            ITI_Timer.Enabled = False ' since end of game, switch of
            endgame()
        Else 'not end of game so set up game to start....
            Prepare_for_next_question()
            Start_of_trial = eventTime.Subtract(startTime).TotalSeconds
            Start_Trial_Timer.Enabled = True
            quest = SelectOrder(quest_num)
            ActionBox.Visible = True
        End If
    End Sub
```

```
    'eventTime = Now
    'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
eventTime.Subtract(startTime).TotalSeconds & " ", True)
```

Also puts a pause before starting a new trial – also set at one millisecond

```
    Private Sub ITI_Timer_Tick(ByVal sender As System.Object,
ITI_Timer.Tick
        ITI_Timer.Enabled = False
        ActionBox.Image = Nothing
        run_game()
    End Sub
```

```
    Private Sub Start_Trial_Timer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Start_Trial_Timer.Tick
        eventTime = Now        'Out(&HE050S, &H1S) ' EVENT 1 Starts
        'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
eventTime.Subtract(startTime).TotalSeconds & " ", True)
        Start_Trial_Timer.Enabled = False
        Trial_Timer.Enabled = True
        Question_responded = 0
        ButtOpt1.Visible = False
        ButtOpt2.Visible = False
        ButtOpt3.Visible = False
        ButtOpt4.Visible = False
        Question.Text = questions(quest, 0) ' + " " + Str(quest)
        ButtOpt1.Text = questions(quest, 1)
```

New trial starts, load up answers into button boxes – one of which is made visible.

```
        ButtOpt2.Text = questions(quest, 2)
        ButtOpt3.Text = questions(quest, 3)
        ButtOpt4.Text = questions(quest, 4)
        GameProgress.Text = "Q:" + Str(quest_num)
        Taking_Answers = 1
        ans = 0
        start_of_trial = eventTime.Subtract(startTime).TotalSeconds
        PlayWackerMole()
    End Sub
```

Randomly chooses where the next option will appear

```
    Public Sub ran_loc_and_opt()
        eventTime = Now
        If action = 1 Then loc_x = MyRandom.Next(x_lo_lim, x_hi_lim)
        If action = 1 Then loc_y = MyRandom.Next(y_lo_lim, y_hi_lim)
        cor_incor = MyRandom.Next(1, 3)
        If cor_incor = 2 Then Opt = MyRandom.Next(2, 5) Else Opt = 1

        eventTime = Now
        start_of_option = eventTime.Subtract(startTime).TotalSeconds
        'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
eventTime.Subtract(startTime).TotalSeconds & " ", True)
        'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), vbNewLine,
True)
        Question_responded = 0
    End Sub
```

States how long each option remains on the screen

```
    Private Sub IntOptPause_Timer_Tick(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles IntOptPause_Timer.Tick
        ButtOpt1.Visible = False
        ButtOpt2.Visible = False
        ButtOpt3.Visible = False
        ButtOpt4.Visible = False
        If Question_responded = 0 Then
            record_start_of_data_line()
            My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "NR" & " ",
True)
            eventTime = Now
            My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
eventTime.Subtract(startTime).TotalSeconds & " ", True)
            My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), vbNewLine,
True)
        End If
        If Taking_Answers = 1 Then PlayWackerMole() Else ActionFeedback()
    End Sub
```

Loads up a random option in a random place.

```
    Public Sub PlayWackerMole()
        ButtOpt1.BackColor = Color.Silver
        ButtOpt2.BackColor = Color.Silver
        ButtOpt3.BackColor = Color.Silver
        ButtOpt4.BackColor = Color.Silver
        IntOptPause_Timer.Enabled = True
        IntOptPause_Timer.Interval = disp_interval
        ran_loc_and_opt()
```

```
        Traj = MyRandom.Next(1, 13)
        x_t = Trajectory(Traj, 1)
        y_t = Trajectory(Traj, 2)
        If action = 0 Then
            loc_x = 205
            loc_y = 326
        End If
        Select Case Opt
            Case 1
                ButtOpt1.Visible = True
                ButtOpt1.Location = New Point(loc_x, loc_y)
            Case 2
                ButtOpt2.Visible = True
                ButtOpt2.Location = New Point(loc_x, loc_y)
            Case 3
                ButtOpt3.Visible = True
                ButtOpt3.Location = New Point(loc_x, loc_y)
            Case 4
                ButtOpt4.Visible = True
                ButtOpt4.Location = New Point(loc_x, loc_y)
        End Select
        First_miss = 0
    End Sub
```

```
    Private Sub Trav1_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Trav1.Tick      'makes the option buttons move
        loc_x = loc_x + (x_t)
        loc_y = loc_y + (y_t)
        If (loc_x < x_lo_lim) Or (loc_x > x_hi_lim) Then x_t = -x_t
        If (loc_y < y_lo_lim) Or (loc_y > y_hi_lim) Then y_t = -y_t
        ButtOpt1.Location = New Point(loc_x, loc_y) 'ButOpt1,2,3,4 are the option buttons you press to
indicate choice
        ButtOpt2.Location = New Point(loc_x, loc_y)
        ButtOpt3.Location = New Point(loc_x, loc_y)
        ButtOpt4.Location = New Point(loc_x, loc_y)
    End Sub
```

Makes the option move around

```
    Private Sub Trial_Timer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Trial_Timer.Tick
        Trial_ends()
    End Sub
```

```
    Public Sub Trial_ends()
        eventTime = Now      ' Out(&HE050S, &H10S) ' EVENT 3,4 ends, 5 Starts
        If Question_response = 0 Then record_question_response()
        'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), vbNewLine &
eventTime.Subtract(startTime).TotalSeconds & " ", True)
        'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), vbNewLine,
True)
        WellDone.Visible = False
        IntOptPause_Timer.Enabled = False
        ButtOpt1.Visible = False
        ButtOpt2.Visible = False
```

End of the trial, records time and options disappear.

```
        ButtOpt3.Visible = False
        ButtOpt4.Visible = False
        Trial_Timer.Enabled = False
        ITI_Timer.Enabled = True
        Taking_Answers = 0
    End Sub
```

```
    Public Sub ActionFeedback()
        ActionFeedbackTimer.Enabled = True
        If ans = 1 Then
            WellDone.BackColor = Color.LightGreen
            WellDone.Visible = True
            WellDone.Text = questions(quest, 4 + NAns + Question_response)
            Player_score_display.Text = Player_Total_Score
            Player_Speed_dial.Text = Player_Total_Speed

        End If
        If ans = 0 Then
            WellDone.BackColor = Color.Red
            WellDone.Visible = True
            WellDone.Text = questions(quest, 4 + NAns + Question_response)
        End If
    End Sub
```

Gives feedback on response marked

```
    Public Sub Prepare_for_next_question()
        quest_num = quest_num + 1
        Points_available.Text = 10
        Points_available.ForeColor = Color.White
        Question_response = 0
        Taking_Answers = 0
        Player_Turn_Score = 0
        Player_score_display.BackColor = Color.Gray
        Player_score_display.ForeColor = Color.White
    End Sub
    Private Sub Stop_Button_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Stop_Button.Click
        Me.Close()
    End Sub
```

Gets new question ready

```
    Public Sub record_question_response()
        eventTime = Now ' If competitor_taking_answers = 1 Then Out(&HE050S, &H8S) Else
Out(&HE050S, &HCS) ' EVENT 3 ends continues, 4 Starts
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
eventTime.Subtract(startTime).TotalSeconds & " ", True)
        Question_responded = 1
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), vbNewLine,
True)
    End Sub
```

Records question response

```
    Public Sub read_questions()
        Dim objfile As New System.IO.StreamReader(cfg_data(1) + "\" + cfg_data(2) + ".txt")
        strquest = objfile.ReadLine()
        Do Until strquest Is Nothing
            quest = quest + 1
```

Reads in questions from file

```
            For N = 0 To 4 + NAns + 4
                questions(quest, N) = strquest
                strquest = objfile.ReadLine()
            Next
        Loop
        objfile.Close()
        objfile.Dispose()
    End Sub
```

```
    Public Sub endgame()
        btnNew.BackColor = Color.Red
        Player_score_display.BackColor = Color.Red
        lblMessage.Visible = True
        lblMessage.Text = "GAME OVER"
    End Sub
```

End of game

```
    Private Sub ButtOpt1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles ButtOpt1.Click
        If Taking_Answers = 1 Then
            ButtOpt1.BackColor = Color.Aqua
            Question_response = 1
            mark_hit()
        End If
    End Sub
```

Following 4 subroutines are almost identical – they represent what happens when the response option is clicked

---

```
    Private Sub ButtOpt2_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles ButtOpt2.Click
        If Taking_Answers = 1 Then
            ButtOpt2.BackColor = Color.Aqua
            Question_response = 2
            mark_hit()
        End If
    End Sub
```

```
    Private Sub ButtOpt3_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles ButtOpt3.Click
        If Taking_Answers = 1 Then
            ButtOpt3.BackColor = Color.Aqua
            Question_response = 3
            mark_hit()
        End If
    End Sub
```

```
    Private Sub ButtOpt4_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles ButtOpt4.Click
        If Taking_Answers = 1 Then
            ButtOpt4.BackColor = Color.Aqua
            Question_response = 4
            mark_hit()
        End If
    End Sub
```

Marks the response and increases score by 10 points if correct

---

```
    Private Sub mark_hit()
        'If Trav1.Interval > TRAV_I Then Trav1.Interval = Trav1.Interval - TRAV_I 'if hit, then reduce
interval between option moving to next position, i.e. increase speed
```

```
        For Me.PossAns = 1 To NAns
            If Question_response = questions(quest, 5 + PossAns - 1) Then
                ans = 1
                Player_Total_Score = Player_Total_Score + 10
                Player_Total_Speed = (200000 / disp_interval)
                Player_Speed_dial.Text = Player_Total_Speed
            End If
        Next PossAns
        If ans = 1 Then
            record_start_of_data_line()
            My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "CH" & " ",
True)
        Else
            record_start_of_data_line()
            My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "IH" & " ",
True)
        End If
        update_time_on_screen()
        If Trav1.Interval > TRAV_I Then Trav1.Interval = Trav1.Interval - TRAV_I
        record_question_response()
        Taking_Answers = 0
        lblMessage.Text = CStr(disp_interval) & "   " & CStr(Trav1.Interval)
    End Sub
```

```
    Private Sub mark_missed_answer()
        Question_response = Opt
        missed_ans = 0
```

Marks the missed responses

```
        For Me.PossAns = 1 To NAns
            If (Question_response = questions(quest, 5 + PossAns - 1) And disp_interval > DISP_I And
First_miss = 0) Then ' ANSWER IS CORRECT
                disp_interval = disp_interval - DISP_I
                missed_ans = 1
            End If
        Next PossAns
        If missed_ans = 1 Then
            record_start_of_data_line()
            My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "CM" & " ",
True)
        Else
            record_start_of_data_line()
            My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "IM" & " ",
True)
        End If
        If (missed_ans = 0 And First_miss = 0) Then disp_interval = disp_interval + DISP_I
        record_question_response()
        Player_Total_Speed = (200000 / disp_interval)
        Player_Speed_dial.Text = Player_Total_Speed
        lblMessage.Text = CStr(disp_interval) & "   " & CStr(Trav1.Interval)
        First_miss = 1
    End Sub
```

```
   Private Sub ActionFeedbackTimer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles ActionFeedbackTimer.Tick
      ActionFeedbackTimer.Enabled = False
      Trial_ends()
   End Sub
```

```
   Private Sub selector_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles Selector.Click
      If Taking_Answers = 1 Then
         ButtOpt1.BackColor = Color.Aqua
         ButtOpt2.BackColor = Color.Aqua
         ButtOpt3.BackColor = Color.Aqua
         ButtOpt4.BackColor = Color.Aqua
         Question_response = Opt
         mark_hit()
         record_question_response()
      End If
   End Sub
```

Selector button for the static condition

```
   Private Sub PictureBox1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles PictureBox1.Click
      Trav1.Interval = Trav1.Interval + TRAV_I 'if hit, then increase interval between option moving to next position, i.e. decrease speed
      mark_missed_answer()

   End Sub
   Private Sub WellDone_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles WellDone.Click

   End Sub
```

New trial starts, loads up answers into button boxes, one of which is made visible

---

```
   Public Sub update_time_on_screen()
      If (ans = 1 And disp_interval > DISP_I) Then disp_interval = disp_interval - DISP_I
      ' if answer correct, reduce interval between options appearing - i.e.  less time on screen
      If ans = 0 Then disp_interval = disp_interval + DISP_I
      ' if answer incorrect, increase interval between options appearing - i.e. more time on screen

   End Sub
```

```
   Public Sub record_start_of_data_line()
      My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), start_of_trial & " ", True)
      My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), quest & " " & questions(quest, 5) & " ", True) ' COLUMN 2,3 = question and answer
      My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), start_of_option & " ", True)
   End Sub
End Class
```

Records information on file.

Appendix XI. Game-like task 2 Code

```
Option Strict Off
Option Explicit On
'Module InpOut32_Declarations ' ignore this stuff - it's for recording on BIOPAC
'Inp and Out declarations for port I/O using inpout32.dll.
'Public Declare Function Inp Lib "inpout32.dll" Alias "Inp32" (ByVal PortAddress As Short) As Short
'Public Declare Sub Out Lib "inpout32.dll" Alias "Out32" (ByVal PortAddress As Short, ByVal Value As Short)
'End Module
Public Class Form1
    Inherits System.Windows.Forms.Form
    Public Function MyTime() As String
        MyTime = Format(Now, "HH:mm:ss:")
    End Function
    Dim startTime, eventTime, startTrial, trialTime, screenTime, time_on_screen As DateTime
    Dim quest As Integer ' this variable used to step through the questions
    Dim quest_num As Integer ' this is where we are in game - 1 = first question presented, 2 = 2nd etc
    Dim candidate, taken As Integer
    Dim Taking_Answers As Integer ' indicates when answers via keyboard are acceptable
    Dim Question_responded As Integer
    Dim Question_response As Integer
    Dim Player_Total_Score, Player_Total_Speed As Integer
    Dim start_of_trial, start_of_option, prev_trial_time, delay As Double
    Dim alt As Integer
    Dim ans, missed_ans, x_t_1, y_t_1, x_t_2, y_t_2, x_t_3, y_t_3, x_t_4, y_t_4 As Integer
    Dim numquest As Integer ' this is the total number of questions in the game,questions per slide, slide
number
    Dim cfg_data(200), questions(100, 20), questions_na(100, 20) As String
    Dim x_lo_lim, x_hi_lim, y_lo_lim, y_hi_lim, DISP_I, TRAV_I, X_sights, Y_line As Integer
    Dim SelectOrder(100), screen_order(4), colour_order(4), trial_order(5), action, no_action, NAns, PossAns,
disp_interval, rpt_q, block, First_miss As Integer
    Dim loc_x_1, loc_y_1, loc_x_2, loc_y_2, loc_x_3, loc_y_3, loc_x_4, loc_y_4 As Integer
    Dim cloud_x_1, cloud_y_1, cloud_x_2, cloud_y_2, cloud_x_3, cloud_y_3
    Dim strcfg, strquest, strquest_na, strpoints, L_R As String
    Dim MyRandom As New Random
    Dim Trajectory(12, 2) As Integer
    Dim X_trajectory, Y_trajectory, Traj, Trajx(4), shoot As Integer
    Dim x_min, x_max, box_x, box_y, act_or_not, TRAV1_INT As Integer
    Dim point1, point2, point3, point4, point5, point6, point7 As Point
    ' unwanted variables Dim x_t, y_t, Opt, cor_incor, loc_x, loc_y, test, slide, Player_Turn_Score  as integer
    Dim x_corr, y_corr, rot, corr_butt(4), incorr_butt(4) As Integer
    Dim action_time_on_screen, na_time_on_screen As Double
    Dim WithEvents Player As System.Windows.Forms.TextBox
    Public Sub form1_loadquest(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
MyBase.Load
        x_corr = 75
        y_corr = 55 ' correction for not anchoring picture of explosion at centre!
        rot = 1
        ' alt = 0
        'Trajectory(1, 1) = 0
        ' Trajectory(1, 2) = 5
        Trajectory(2, 1) = 4
        Trajectory(2, 2) = 1
        Trajectory(3, 1) = 3
```

```
Trajectory(3, 2) = 4
Trajectory(4, 1) = 0
Trajectory(4, 2) = 5
Trajectory(5, 1) = 1
Trajectory(5, 2) = 4
Trajectory(1, 1) = 4
Trajectory(1, 2) = 3
box_x = 70 ' size of ButtOpt (width)
box_y = 70 'size of ButtOpt (height)
ButtOpt1.Size = New Point(box_x, box_y)
ButtOpt2.Size = New Point(box_x, box_y)
ButtOpt3.Size = New Point(box_x, box_y)
ButtOpt4.Size = New Point(box_x, box_y)

x_min = 10
x_max = 980
X_sights = 490
Y_line = 300
LineShape1.StartPoint = New Point(10, Y_line)
LineShape1.EndPoint = New Point(980, Y_line)
LineShape2.StartPoint = New Point(X_sights, Y_line)
LineShape2.EndPoint = New Point(X_sights, Y_line)
Label1.Visible = False
Label2.Visible = False
Label3.Visible = False
lblMessage.Location = New Point(150, 200)
lblMessage.Size = New Point(666, 160)
lblMessage.Text = "SHOOT THE PRIME!"
lblMessage.Visible = True


For n = 6 To 10
   Trajectory(n, 1) = -Trajectory(n - 5, 1)
   Trajectory(n, 2) = -Trajectory(n - 5, 2)
Next n
' lblMessage.Text = Trajectory(8, 1) & " " & Trajectory(8, 2)
'cfg file:
'01:home directory for files
'02:question file name
'03:learning content directory name
'06:data file name
'07:number of questions (should correspond with size of 02,03 and 05)
'08:=1 if Active gaming
'10:ITI_Timer.Interval = time before the ITI = Gaming Feedback Time
'11:Start_Trial_Timer.Interval = time before Trial starts = ITI ENDS - BIOPAC Digital Ch 1 Event starts = 
Learning presented
'14:Trial_Timer.Interval = time before trial ends
'20:number of correct answers
'21:number of times to repeat questions
'22:Option Interval
'23:Travel Interval
'25: = question file name for no action
disp_interval = 10000
TRAV1_INT = 30
'  Trav1.Interval = 100
```

```
    x_lo_lim = 50
    x_hi_lim = 700
    y_lo_lim = 50
    y_hi_lim = 450
    'ActionBox.Location = New Point(x_lo_lim, y_lo_lim)
    'ActionBox.Width = x_hi_lim - x_lo_lim + 68 ' 68 is width of box
    'ActionBox.Height = y_hi_lim - y_lo_lim + 38 ' 38 is height of box
End Sub
```

```
Public Sub ArrangeQuestionOrder()
    ' SelectOrder will contain the randomised order of questions presented
    For Me.block = 1 To rpt_q
        SelectOrder(1 + (block - 1) * numquest) = MyRandom.Next(numquest) + 1
        For N = 2 To numquest
            candidate = MyRandom.Next(numquest) + 1
            taken = 0
            For SO = 1 To N - 1
                If SelectOrder(SO + (block - 1) * numquest) = candidate Then taken = 1
            Next
            If taken = 0 Then
                SelectOrder(N + (block - 1) * numquest) = candidate
            Else : N = N - 1
            End If
        Next
    Next
    numquest = numquest * rpt_q
End Sub
```

```
Public Sub ArrangeScreenOrder()
    ' Screen_Order will contain the randomised order of questions presented in the boxes
    screen_order(1) = MyRandom.Next(4) + 1
    For N = 2 To 4
        candidate = MyRandom.Next(4) + 1
        taken = 0
        For SO = 1 To N - 1
            If screen_order(SO) = candidate Then taken = 1
        Next
        If taken = 0 Then
            screen_order(N) = candidate
        Else : N = N - 1
        End If
    Next
End Sub
```

```
Public Sub ArrangeColourOrder()
    'Colour_Order will contain the randomised order of colours presented in the boxes
    colour_order(1) = MyRandom.Next(4) + 1
    For N = 2 To 4
        candidate = MyRandom.Next(4) + 1
        taken = 0
        For SO = 1 To N - 1
            If colour_order(SO) = candidate Then taken = 1
        Next
        If taken = 0 Then
            colour_order(N) = candidate
        Else : N = N - 1
        End If
    Next
```

```
    End Sub
    Public Sub btnNew_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
btnNew.Click
        Dim cfgfile As New System.IO.StreamReader(cfgbox.Text + ".txt")
        Dim lengt, cfg As Integer
        ' lblMessage.Text = CStr(disp_interval) & "   " & CStr(Trav1.Interval)
        btnNew.BackColor = Color.WhiteSmoke
        act_or_not = 1
        ' If act_or_not = 1 Then act_or_not = 0 Else act_or_not = 1
        'quest = 0
        lblMessage.Visible = False
        strcfg = cfgfile.ReadLine()
        Do Until strcfg Is Nothing
            For cfg = 1 To 25 ' 21 because that takes strcfg to nothing
                cfg_data(cfg) = strcfg
                strcfg = cfgfile.ReadLine()
                lengt = Microsoft.VisualBasic.Len(cfg_data(cfg))
                If lengt > 3 Then cfg_data(cfg) = Microsoft.VisualBasic.Right(cfg_data(cfg), lengt - 3)
            Next
        Loop
        cfgfile.Close()
        cfgfile.Dispose()
        numquest = cfg_data(7)
        action = cfg_data(8) 'do question move?
        ITI_Timer.Interval = Int(cfg_data(10)) 'Inter-trial interval
        Start_Trial_Timer.Interval = cfg_data(11) ' Time for learning before question - that's zero in your study?
        Trial_Timer.Interval = cfg_data(14) ' how long the question lasts for
        NAns = cfg_data(20) ' number of times that the correct answer appears
        rpt_q = cfg_data(21) ' number of times that question gets repeated
        DISP_I = cfg_data(22) 'increment by which duration of the display of option is being
increased/decreased - decides how rapidly options are appearing/disappearing
        TRAV_I = cfg_data(23) 'increment by which delay before moving to next position is being
increased/decreased
        ' test = cfg_data(24)
        'no_action = cfg_data(25) 'static trial corpus

        If action = 1 Then
            Trav1.Enabled = True 'starts Trav1 is the timer for the answer travelling. Every time it goes off, the
answer moves.
            Selector.Visible = False

        End If

        read_questions() ' goes to a routine that loads up the questions into questions(quest, N) where quest is
question number e.g. Q7 and if N = 0, its the question 7, N=1 it's option 1 for question 7 etc
        read_questions_noaction()
        ArrangeQuestionOrder() ' produces a random sequence of integers (in SelectOrder) from 1 to
NumQuest, for randomising selection of questions
        ArrangeScreenOrder()

        Taking_Answers = 0 ' this means that its not presently possible to enter an answer
        Player_Total_Score = 0 ' set player score to 0
        Player_Total_Speed = 0
        Player_score_display.Text = Player_Total_Score ' display the player's score
```

```
        Player_Speed_dial.Text = Player_Total_Speed 'display the player's speed based on adaptive
disp_interval
        'Out(&HE050S, &H0S) ' all EVENTs at zero
        ' Below writes an introductory line on data file - includes DOB etc
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), vbNewLine & "NEW
PARTICIPANT" & " " & DOB.Text & " " & cfgbox.Text, True)
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), vbNewLine, True)
        startTime = Now ' store the start time of the game
        run_game()
        cfgbox.Visible = False
        DOB.Visible = False
        btnNew.Visible = False

    End Sub
```

```
    Public Sub run_game()
        eventTime = Now ' COLUMN 1 = start of learn
        If quest_num = numquest Then
            ITI_Timer.Enabled = False ' since end of game, switch off countdown to next trial
            endgame()
        Else 'not end of game so set up game to start....
            Prepare_for_next_question()
            start_of_trial = eventTime.Subtract(startTime).TotalSeconds
            Start_Trial_Timer.Enabled = True
            quest = SelectOrder(quest_num)
            'ActionBox.Visible = False
        End If
    End Sub
```

```
    'eventTime = Now
    'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
eventTime.Subtract(startTime).TotalSeconds & " ", True)
    Private Sub ITI_Timer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
ITI_Timer.Tick
        ITI_Timer.Enabled = False
        'ActionBox.Image = Nothing
        run_game()
    End Sub
```

```
    Private Sub Start_Trial_Timer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Start_Trial_Timer.Tick
        eventTime = Now         'Out(&HE050S, &H1S) ' EVENT 1 Starts
        startTrial = Now
        If act_or_not = 1 Then act_or_not = 0 Else act_or_not = 1
        If act_or_not = 1 Then Trav1.Interval = TRAV1_INT
        If act_or_not = 0 Then Trav1.Interval = 50000

        Start_Trial_Timer.Enabled = False
        Trial_Timer.Enabled = True
        Question_responded = 0
        Question.Text = questions(quest, 0) ' + " " + Str(quest)
        If act_or_not = 1 Then
            ButtOpt1.Text = questions(quest, 1)
            ButtOpt2.Text = questions(quest, 2)
            ButtOpt3.Text = questions(quest, 3)
            ButtOpt4.Text = questions(quest, 4)

        Else
```

```
        ArrangeScreenOrder()

        ButtOpt1.Text = questions_na(quest, screen_order(1))
        ButtOpt2.Text = questions_na(quest, screen_order(2))
        ButtOpt3.Text = questions_na(quest, screen_order(3))
        ButtOpt4.Text = questions_na(quest, screen_order(4))
    End If

    GameProgress.Text = "Q:" + Str(quest_num)
    Taking_Answers = 1
    ans = 0
    start_of_trial = eventTime.Subtract(startTime).TotalSeconds
    PlayWackerMole()
End Sub
```

```
Public Sub ran_loc_and_opt()
    eventTime = Now
    If act_or_not = 1 Then loc_x_1 = MyRandom.Next(x_lo_lim, x_hi_lim)
    If act_or_not = 1 Then loc_y_1 = MyRandom.Next(y_lo_lim, y_hi_lim)
    If act_or_not = 1 Then loc_x_2 = MyRandom.Next(x_lo_lim, x_hi_lim)
    If act_or_not = 1 Then loc_y_2 = MyRandom.Next(y_lo_lim, y_hi_lim)
    If act_or_not = 1 Then loc_x_3 = MyRandom.Next(x_lo_lim, x_hi_lim)
    If act_or_not = 1 Then loc_y_3 = MyRandom.Next(y_lo_lim, y_hi_lim)
    If act_or_not = 1 Then loc_x_4 = MyRandom.Next(x_lo_lim, x_hi_lim)
    If act_or_not = 1 Then loc_y_4 = MyRandom.Next(y_lo_lim, y_hi_lim)

    LineShape1.Visible = True
    LineShape2.Visible = True
    LineShape2.StartPoint = New Point(X_sights, Y_line - 20)
    LineShape2.EndPoint = New Point(X_sights, Y_line + 20)
    Label1.Visible = True
    Label2.Visible = True
    Label3.Visible = True

    If act_or_not = 0 Then
        loc_x_1 = 158
        loc_y_1 = 171
        loc_x_2 = 736
        loc_y_2 = 171
        loc_x_3 = 158
        loc_y_3 = 402
        loc_x_4 = 736
        loc_y_4 = 402
        LineShape1.Visible = False
        LineShape2.Visible = False

        ButtOpt1.BackColor = Color.FromArgb(209, 162, 67)
        Label1.Visible = False
        Label2.Visible = False
        Label3.Visible = False

    End If

    eventTime = Now
    start_of_option = eventTime.Subtract(startTime).TotalSeconds
    Question_responded = 0
```

```
  End Sub
```

```
  Public Sub PlayWackerMole()
    X_sights = 490
    ArrangeColourOrder()
    set_colour()
    ran_loc_and_opt()

    Trajx(1) = MyRandom.Next(1, 10) ' to avoid overlapping of trajectories
    For N = 2 To 4
      candidate = MyRandom.Next(1, 10)
      taken = 0
      For X = 1 To N - 1
        If Trajx(X) = candidate Then taken = 1
      Next
      If taken = 0 Then
        Trajx(N) = candidate
      Else : N = N - 1
      End If
    Next
    'lblMessage.Text = Trajx(1) & " " & Trajx(2) & " " & Trajx(3) & " " & Trajx(4) & " "

    'Traj = MyRandom.Next(1, 13)
    x_t_1 = Trajectory(Trajx(1), 1)
    y_t_1 = Trajectory(Trajx(1), 2)
    'Traj = MyRandom.Next(1, 13)
    x_t_2 = Trajectory(Trajx(2), 1)
    y_t_2 = Trajectory(Trajx(2), 2)
    'Traj = MyRandom.Next(1, 13)
    x_t_3 = Trajectory(Trajx(3), 1)
    y_t_3 = Trajectory(Trajx(3), 2)
    'Traj = MyRandom.Next(1, 13)
    x_t_4 = Trajectory(Trajx(4), 1)
    y_t_4 = Trajectory(Trajx(4), 2)

    ButtOpt1.Visible = True
    ButtOpt2.Visible = True
    ButtOpt3.Visible = True
    ButtOpt4.Visible = True
    ButtOpt1.Location = New Point(loc_x_1, loc_y_1)
    ButtOpt2.Location = New Point(loc_x_2, loc_y_2)
    ButtOpt3.Location = New Point(loc_x_3, loc_y_3)
    ButtOpt4.Location = New Point(loc_x_4, loc_y_4)

    First_miss = 0

  End Sub
```

```
  Private Sub Trav1_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles Trav1.Tick
'makes the option buttons move
    ' 1
    loc_x_1 = loc_x_1 + (x_t_1)
    loc_y_1 = loc_y_1 + (y_t_1)
    If (loc_x_1 < x_lo_lim) Or (loc_x_1 > x_hi_lim) Then x_t_1 = -x_t_1
    If (loc_y_1 < y_lo_lim) Or (loc_y_1 > y_hi_lim) Then y_t_1 = -y_t_1
    ButtOpt1.Location = New Point(loc_x_1, loc_y_1) 'ButOpt1,2,3,4 are the option buttons you press to
indicate choice
```

```
        ButtOpt2.Location = New Point(loc_x_2, loc_y_2)
        ButtOpt3.Location = New Point(loc_x_3, loc_y_3)
        ButtOpt4.Location = New Point(loc_x_4, loc_y_4)
        ' 2
        loc_x_2 = loc_x_2 + (x_t_2)
        loc_y_2 = loc_y_2 + (y_t_2)
        If (loc_x_2 < x_lo_lim) Or (loc_x_2 > x_hi_lim) Then x_t_2 = -x_t_2
        If (loc_y_2 < y_lo_lim) Or (loc_y_2 > y_hi_lim) Then y_t_2 = -y_t_2
        ButtOpt1.Location = New Point(loc_x_1, loc_y_1) 'ButOpt1,2,3,4 are the option buttons you press to
indicate choice
        ButtOpt2.Location = New Point(loc_x_2, loc_y_2)
        ButtOpt3.Location = New Point(loc_x_3, loc_y_3)
        ButtOpt4.Location = New Point(loc_x_4, loc_y_4)
        '3
        loc_x_3 = loc_x_3 + (x_t_3)
        loc_y_3 = loc_y_3 + (y_t_3)
        If (loc_x_3 < x_lo_lim) Or (loc_x_3 > x_hi_lim) Then x_t_3 = -x_t_3
        If (loc_y_3 < y_lo_lim) Or (loc_y_3 > y_hi_lim) Then y_t_3 = -y_t_3
        ButtOpt1.Location = New Point(loc_x_1, loc_y_1) 'ButOpt1,2,3,4 are the option buttons you press to
indicate choice
        ButtOpt2.Location = New Point(loc_x_2, loc_y_2)
        ButtOpt3.Location = New Point(loc_x_3, loc_y_3)
        ButtOpt4.Location = New Point(loc_x_4, loc_y_4)
        '4
        loc_x_4 = loc_x_4 + (x_t_4)
        loc_y_4 = loc_y_4 + (y_t_4)
        If (loc_x_4 < x_lo_lim) Or (loc_x_4 > x_hi_lim) Then x_t_4 = -x_t_4
        If (loc_y_4 < y_lo_lim) Or (loc_y_4 > y_hi_lim) Then y_t_4 = -y_t_4
        ButtOpt1.Location = New Point(loc_x_1, loc_y_1) 'ButOpt1,2,3,4 are the option buttons you press to
indicate choice
        ButtOpt2.Location = New Point(loc_x_2, loc_y_2)
        ButtOpt3.Location = New Point(loc_x_3, loc_y_3)
        ButtOpt4.Location = New Point(loc_x_4, loc_y_4)
    End Sub
```

```
    Private Sub Trial_Timer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Trial_Timer.Tick
        Trial_ends()
    End Sub
```

```
    Public Sub Trial_ends()
        eventTime = Now       ' Out(&HE050S, &H10S) ' EVENT 3,4 ends, 5 Starts
        If Question_responded = 0 Then mark_timeout()
        WellDone.Visible = False
        IntOptPause_Timer.Enabled = False
        Trial_Timer.Enabled = False
        ITI_Timer.Enabled = True
        Taking_Answers = 0
        Explosion.Visible = False

    End Sub
```

```
    Public Sub ActionFeedback()
        ActionFeedbackTimer.Enabled = True
        ' time stamp
        screenTime = Now
        'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), eventTime & " " &
screenTime & " ", True)
```

```
        If Question_responded = 1 Then My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6)
+ ".txt"), screenTime.Subtract(startTrial).TotalSeconds & " ", True)
        'If Question_responded = 0 Then My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6)
+ ".txt"), screenTime.Subtract(startTrial).TotalSeconds & " ", True)
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), vbNewLine, True)

        'If test = 0 Then To use the same game as tester but with the static form - possibility discarded
        'If ans = 1 Then
        'WellDone.BackColor = Color.FromArgb(98, 196, 81)
        'WellDone.Visible = True

        'If act_or_not = 1 Then
        'WellDone.Text = questions(quest, 4 + NAns + Question_response)
        'Else
        'WellDone.Text = questions_na(quest, 4 + NAns + Question_response)

        'End If
        Player_score_display.Text = Player_Total_Score
        Player_Speed_dial.Text = Player_Total_Speed
        'End If
        'End If
        'If test = 0 Then
        'If ans = 0 Then
        'WellDone.BackColor = Color.Red
        'WellDone.Visible = True
        'If act_or_not = 1 Then
        'WellDone.Text = questions(quest, 4 + NAns + Question_response)
        'Else
        'WellDone.Text = questions_na(quest, 4 + NAns + Question_response)

        'End If
        'End If
    End Sub
```

```
    Public Sub Prepare_for_next_question()
        quest_num = quest_num + 1
        Points_available.Text = 10
        Points_available.ForeColor = Color.White
        Question_response = 0
        Taking_Answers = 0
        ' Player_Turn_Score = 0
        Player_score_display.BackColor = Color.Gray
        Player_score_display.ForeColor = Color.White
        Trav1.Enabled = True

    End Sub
```

```
    Private Sub Stop_Button_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Stop_Button.Click
        Me.Close()
    End Sub
    Public Sub record_question_response()
        eventTime = Now ' If competitor_taking_answers = 1 Then Out(&HE050S, &H8S) Else Out(&HE050S,
&HCS) ' EVENT 3 ends continues, 4 Starts

        If act_or_not = 1 Then
            action_time_on_screen = action_time_on_screen + eventTime.Subtract(startTrial).TotalSeconds
```

```
        Else
            na_time_on_screen = na_time_on_screen + eventTime.Subtract(startTrial).TotalSeconds

        End If

        'If act_or_not = 1 Then
        'If quest_num > 1 Then
        'If time_on_screen.Second > screenTime.Subtract(eventTime).TotalSeconds Then
        'If prev_trial_time < eventTime.Subtract(startTrial).TotalSeconds Then
        If act_or_not = 0 Then
            If na_time_on_screen < action_time_on_screen Then
                Feedback_delay.Interval = (action_time_on_screen - na_time_on_screen) * 1000
                na_time_on_screen = na_time_on_screen + Feedback_delay.Interval / 1000
            Else
                If na_time_on_screen > action_time_on_screen Then
                    'action_time_on_screen = na_time_on_screen - action_time_on_screen
                    na_time_on_screen = na_time_on_screen + 1 / 1000
                    Feedback_delay.Interval = 1
                End If
            End If
        End If
        ' If act_or_not = 1 Then
        'If na_time_on_screen > action_time_on_screen Then
        'Feedback_delay.Interval = (na_time_on_screen - action_time_on_screen) * 1000
        'End If
        'End If

        'End If
        prev_trial_time = eventTime.Subtract(startTrial).TotalSeconds
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), 
eventTime.Subtract(startTime).TotalSeconds & " ", True)
        If Question_responded = 0 Then My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) 
+ ".txt"), "0" & " ", True)
        If Question_responded = 1 Then My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) 
+ ".txt"), eventTime.Subtract(startTrial).TotalSeconds & " ", True)
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), 
Feedback_delay.Interval & " ", True)

        'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), prev_trial_time & " ", 
True)
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), action_time_on_screen 
& " ", True)
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), na_time_on_screen & " 
", True)

        If act_or_not = 0 Then
            My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "No_Action" & " ", 
True)
        Else
            My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "Action" & " ", True)
        End If
        'time_on_screen = Date.FromOADate(screenTime.Subtract(eventTime).TotalSeconds)

    End Sub
```

```
    Public Sub read_questions()
```

```
    Dim objfile As New System.IO.StreamReader(cfg_data(1) + "\" + cfg_data(2) + ".txt")
    strquest = objfile.ReadLine()
    quest = 0
    Do Until strquest Is Nothing
      quest = quest + 1
      For N = 0 To 4 + NAns + 4
        questions(quest, N) = strquest
        strquest = objfile.ReadLine()
      Next
    Loop
  End Sub
```

```
  Public Sub read_questions_noaction()
    Dim objfile As New System.IO.StreamReader(cfg_data(1) + "\" + cfg_data(2) + "_na" + ".txt")
    strquest = objfile.ReadLine()
    quest = 0
    Do Until strquest Is Nothing
      quest = quest + 1
      For N = 0 To 4 + NAns + 4
        questions_na(quest, N) = strquest
        strquest = objfile.ReadLine()
      Next
    Loop

  End Sub
```

```
  Public Sub endgame()
    btnNew.BackColor = Color.Red
    Player_score_display.BackColor = Color.Red
    lblMessage.Visible = True
    lblMessage.Location = New Point(150, 200)
    lblMessage.Size = New Point(666, 160)
    lblMessage.Text = "GAME OVER"
    ButtOpt1.Visible = False
    ButtOpt2.Visible = False
    ButtOpt3.Visible = False
    ButtOpt4.Visible = False

  End Sub
```

```
  Private Sub mark_hit()
    For Me.PossAns = 1 To NAns
      If Question_response = questions(quest, 5) Then
        ans = 1
        Player_Total_Score = Player_Total_Score + 10
        Player_Total_Speed = (200000 / disp_interval)
        Player_Speed_dial.Text = Player_Total_Speed
        Player_score_display.Text = CStr(Player_Total_Score)
      End If

      If act_or_not = 1 Then
        If ans = 1 Then
          If Question_response = 1 Then ButtOpt1.BackColor = Color.FromArgb(0, 109, 40)
          If Question_response = 2 Then ButtOpt2.BackColor = Color.FromArgb(0, 109, 40)
          If Question_response = 3 Then ButtOpt3.BackColor = Color.FromArgb(0, 109, 40)
          If Question_response = 4 Then ButtOpt4.BackColor = Color.FromArgb(0, 109, 40)
        End If
```

```
            If ans = 0 Then
                If Question_response = 1 Then ButtOpt1.BackColor = Color.FromArgb(186, 26, 19)
                If Question_response = 2 Then ButtOpt2.BackColor = Color.FromArgb(186, 26, 19)
                If Question_response = 3 Then ButtOpt3.BackColor = Color.FromArgb(186, 26, 19)
                If Question_response = 4 Then ButtOpt4.BackColor = Color.FromArgb(186, 26, 19)
            End If
        End If

        If act_or_not = 0 Then
            If ans = 1 Then
                If Question_response = screen_order(1) Then ButtOpt1.BackColor = Color.FromArgb(0, 109, 40)
                If Question_response = screen_order(2) Then ButtOpt2.BackColor = Color.FromArgb(0, 109, 40)
                If Question_response = screen_order(3) Then ButtOpt3.BackColor = Color.FromArgb(0, 109, 40)
                If Question_response = screen_order(4) Then ButtOpt4.BackColor = Color.FromArgb(0, 109, 40)
            End If

            If ans = 0 Then
                If Question_response = screen_order(1) Then ButtOpt1.BackColor = Color.FromArgb(186, 26, 19)
                If Question_response = screen_order(2) Then ButtOpt2.BackColor = Color.FromArgb(186, 26, 19)
                If Question_response = screen_order(3) Then ButtOpt3.BackColor = Color.FromArgb(186, 26, 19)
                If Question_response = screen_order(4) Then ButtOpt4.BackColor = Color.FromArgb(186, 26, 19)

            End If
        End If

    Next PossAns
    Question_responded = 1
    If ans = 1 Then
        record_start_of_data_line()
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "Correct" & " ", True)
'Records type of answer in primer_data file
    Else
        record_start_of_data_line()
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "Incorrect" & " ",
True)
    End If
    record_question_response()
    Taking_Answers = 0
  End Sub
  Private Sub mark_timeout()
    'Records when question is not responded as Time_out in primer_data file
    If Question_responded = 0 Then
        record_start_of_data_line()
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "Time_out" & " ",
True)
    End If
    record_question_response()
    Taking_Answers = 0

  End Sub
```

```
  Private Sub ActionFeedbackTimer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles ActionFeedbackTimer.Tick
    ActionFeedbackTimer.Enabled = False
    Trial_ends()
  End Sub
```

```
    Private Sub WellDone_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
WellDone.Click

    End Sub
```

```
    Private Sub Explode()
        If act_or_not = 1 Then
            If Question_response = 1 Then
                Trav1.Enabled = False
                Label1.Visible = False
                Label2.Visible = False
                Label3.Visible = False
                Explosion.Visible = True
                ButtOpt1.Visible = True
                ButtOpt2.Visible = True
                ButtOpt3.Visible = True
                ButtOpt4.Visible = True
                Question.Visible = False
                Explosion.Location = New Point(X_sights - 93, 200) 'To make explosion coincide with number shot
                My.Computer.Audio.Play("C:\Documents and Settings\useradmin\My Documents\Visual Studio
2008\Projects\Shoot\Smashing.wav")

            Else
                Trav1.Enabled = False
                Label1.Visible = False
                Label2.Visible = False
                Label3.Visible = False
                My.Computer.Audio.Play("C:\Documents and Settings\useradmin\My Documents\Visual Studio
2008\Projects\Shoot\Computer Error Alert.wav")
                ButtOpt1.Visible = True
                ButtOpt2.Visible = True
                ButtOpt3.Visible = True
                ButtOpt4.Visible = True
                Question.Visible = False

            End If
        End If

        If act_or_not = 0 Then
            If Question_response = 1 Then
                Explosion.Visible = True
                ButtOpt1.Visible = True
                ButtOpt2.Visible = True
                ButtOpt3.Visible = True
                ButtOpt4.Visible = True
                Question.Visible = False
                ' Explosion.Location = New Point(X_sights - 93, 200) 'To make explosion coincide with number shot
                My.Computer.Audio.Play("C:\Documents and Settings\useradmin\My Documents\Visual Studio
2008\Projects\Shoot\Smashing.wav")

            Else
                My.Computer.Audio.Play("C:\Documents and Settings\useradmin\My Documents\Visual Studio
2008\Projects\Shoot\Computer Error Alert.wav")
                ButtOpt1.Visible = True
                ButtOpt2.Visible = True
                ButtOpt3.Visible = True
```

```
            ButtOpt4.Visible = True
            Question.Visible = False
            'Explosion.Visible = False
        End If
    End If

End Sub
```

```
Public Sub record_start_of_data_line()
    My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), start_of_trial & " ",
True)
    My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), quest & " " &
questions(quest, 5) & " ", True) ' COLUMN 2,3 = question and answer
    My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), start_of_option & " ",
True)

End Sub
```

```
Protected Overrides Function ProcessCmdKey(ByRef msg As System.Windows.Forms.Message, ByVal
keyData As System.Windows.Forms.Keys) As Boolean
    If msg.Msg = 256 Then ' WinMsg was a keypress. should always see this value anyway - note from coder
        If act_or_not = 1 Then
            Select Case keyData
                Case Keys.A
                    If X_sights > x_min Then X_sights = X_sights - 10
                    LineShape2.StartPoint = New Point(X_sights, Y_line - 20)
                    LineShape2.EndPoint = New Point(X_sights, Y_line + 20)
                Case Keys.D
                    If X_sights < x_max Then X_sights = X_sights + 10
                    LineShape2.StartPoint = New Point(X_sights, Y_line - 20)
                    LineShape2.EndPoint = New Point(X_sights, Y_line + 20)
                Case Keys.L
                    'If shoot = 0 Then shoot = 1
                    'shooting.Enabled = True
                    ' Option 1
                    If ((loc_x_1 + box_x / 2 - box_x / 2 < X_sights) And (X_sights < loc_x_1 + box_x / 2 + box_x / 2))
Or ((loc_x_2 + box_x / 2 - box_x / 2 < X_sights) And (X_sights < loc_x_2 + box_x / 2 + box_x / 2)) Or ((loc_x_3
+ box_x / 2 - box_x / 2 < X_sights) And (X_sights < loc_x_3 + box_x / 2 + box_x / 2) And (loc_y_3 + box_y / 2 -
box_y / 2 < Y_line)) Or ((loc_x_4 + box_x / 2 - box_x / 2 < X_sights) And (X_sights < loc_x_4 + box_x / 2 +
box_x / 2) And (loc_y_4 + box_y / 2 - box_y / 2 < Y_line)) Then
                        If ((loc_x_1 + box_x / 2 - box_x / 2 < X_sights) And (X_sights < loc_x_1 + box_x / 2 + box_x /
2) And (loc_y_1 + box_y / 2 - box_y / 2 < Y_line) And (Y_line < loc_y_1 + box_y / 2 + box_y / 2)) Then
                            Question_response = 1
                            mark_hit()
                            Explode()
                            ActionFeedback()
                        End If
                        'Option 2
                        If ((loc_x_2 + box_x / 2 - box_x / 2 < X_sights) And (X_sights < loc_x_2 + box_x / 2 + box_x /
2) And (loc_y_2 + box_y / 2 - box_y / 2 < Y_line) And (Y_line < loc_y_2 + box_y / 2 + box_y / 2)) Then
                            'lblMessage.Text = "HIT!"
                            Question_response = 2
                            mark_hit()
                            Explode()
                            ActionFeedback()
                            'WellDone.Visible = True
                            'WellDone.Text = questions(quest, 4 + NAns + Question_response)
```

```
                    End If
                    'OPtion 3
                    If ((loc_x_3 + box_x / 2 - box_x / 2 < X_sights) And (X_sights < loc_x_3 + box_x / 2 + box_x /
2) And (loc_y_3 + box_y / 2 - box_y / 2 < Y_line) And (Y_line < loc_y_3 + box_y / 2 + box_y / 2)) Then
                        'lblMessage.Text = "HIT!"
                        Question_response = 3
                        mark_hit()
                        Explode()
                        ActionFeedback()
                        'WellDone.Visible = True
                        'WellDone.Text = questions(quest, 4 + NAns + Question_response)
                    End If
                    'OPtion 4
                    If ((loc_x_4 + box_x / 2 - box_x / 2 < X_sights) And (X_sights < loc_x_4 + box_x / 2 + box_x /
2) And (loc_y_4 + box_y / 2 - box_y / 2 < Y_line) And (Y_line < loc_y_4 + box_y / 2 + box_y / 2)) Then
                        'lblMessage.Text = "HIT!"
                        Question_response = 4
                        mark_hit()
                        Explode()
                        ActionFeedback()
                    End If
                    'Else : lblMessage.Text = "MISS!"
                End If
            End Select
        End If
        If act_or_not = 0 Then
            'If shoot = 0 Then shoot = 1
            Select Case keyData
                Case Keys.D 'goes clockwise
                    rot = rot + 1
                    If rot = 5 Then rot = 1
                    highlight_box()
                Case Keys.A 'goes anticlockwise
                    rot = rot - 1
                    If rot = 0 Then rot = 4
                    highlight_box()
                Case Keys.L
                    If Keys.L = keyData Then
                        If rot = 1 Then
                            Question_response = screen_order(1)
                            'lblMessage.Text = "hello" & screen_order(1)
                            Explosion.Location = New Point(158 - x_corr, 171 - y_corr)
                        End If
                        If rot = 2 Then
                            Question_response = screen_order(2)
                            'lblMessage.Text = "hello" & screen_order(2)
                            Explosion.Location = New Point(736 - x_corr, 171 - y_corr)
                        End If
                        If rot = 3 Then
                            Question_response = screen_order(4)
                            'lblMessage.Text = "hello" & screen_order(3)
                            Explosion.Location = New Point(736 - x_corr, 402 - y_corr)
                        End If
                        If rot = 4 Then
                            Question_response = screen_order(3)
```

```
                'lblMessage.Text = "hello" & screen_order(4)
                Explosion.Location = New Point(158 - x_corr, 402 - y_corr)
              End If
            End If
            'lblMessage.Text = "hello" & screen_order(4) & rot
            mark_hit()
            Explode()
            Feedback_delay.Enabled = True
          End Select
        End If
      End If
      ' Return MyBase.ProcessCmdKey(msg, keyData) - PHJ: not sure if this needed?!

    End Function
```

```
    Private Sub shooting_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
shooting.Tick
      shoot = 0
      shooting.Enabled = False

    End Sub
```

```
    Private Sub cfgbox_TextChanged(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
cfgbox.TextChanged

    End Sub
```

```
    Public Sub set_colour()
      Select Case colour_order(1)
        Case 1
          ButtOpt1.BackColor = Color.Black
        Case 2
          ButtOpt1.BackColor = Color.Black
        Case 3
          ButtOpt1.BackColor = Color.Black
        Case 4
          ButtOpt1.BackColor = Color.Black
      End Select
      Select Case colour_order(2)
        Case 1
          ButtOpt2.BackColor = Color.Black
        Case 2
          ButtOpt2.BackColor = Color.Black
        Case 3
          ButtOpt2.BackColor = Color.Black
        Case 4
          ButtOpt2.BackColor = Color.Black
      End Select
      Select Case colour_order(3)
        Case 1
          ButtOpt3.BackColor = Color.Black
        Case 2
          ButtOpt3.BackColor = Color.Black
        Case 3
          ButtOpt3.BackColor = Color.Black
        Case 4
          ButtOpt3.BackColor = Color.Black
      End Select
```

```
        Select Case colour_order(4)
            Case 1
                ButtOpt4.BackColor = Color.Black
            Case 2
                ButtOpt4.BackColor = Color.Black
            Case 3
                ButtOpt4.BackColor = Color.Black
            Case 4
                ButtOpt4.BackColor = Color.Black
        End Select

    End Sub
```

```
    Public Sub highlight_box() ' highlights the static boxes in red in order to indicate the one selected
        set_colour()
        Select Case rot
            Case 1
                ButtOpt1.BackColor = Color.FromArgb(209, 162, 67)
            Case 2
                ButtOpt2.BackColor = Color.FromArgb(209, 162, 67)
            Case 3
                ButtOpt4.BackColor = Color.FromArgb(209, 162, 67)
            Case 4
                ButtOpt3.BackColor = Color.FromArgb(209, 162, 67)

        End Select
    End Sub
```

```
    Private Sub Feedback_delay_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Feedback_delay.Tick
        Feedback_delay.Enabled = False
        ActionFeedback()

    End Sub

End Class
```

Appendix XII. Game-like task 2 – Two player Code

```
'This is a game for two players testing the effect of action/no action in learning
Option Strict Off
Option Explicit On
'Module InpOut32_Declarations ' ignore this stuff - it's for recording on BIOPAC
'Inp and Out declarations for port I/O using inpout32.dll.
'Public Declare Function Inp Lib "inpout32.dll" Alias "Inp32" (ByVal PortAddress As Short) As Short
'Public Declare Sub Out Lib "inpout32.dll" Alias "Out32" (ByVal PortAddress As Short, ByVal Value As Short)
'End Module
```

```
Public Class Form1
  Inherits System.Windows.Forms.Form
  Public Function MyTime() As String
    MyTime = Format(Now, "HH:mm:ss:")
  End Function
  Dim startTime, eventTime, startTrial, trialTime, screenTime, time_on_screen As DateTime
  Dim quest As Integer ' this variable used to step through the questions
  Dim quest_num As Integer ' this is where we are in game - 1 = first question presented, 2 = 2nd etc
  Dim candidate, taken As Integer
  Dim Taking_Answers As Integer ' indicates when answers via keyboard are acceptable
  Dim Question_responded_P1, Question_responded_P2 As Integer
  Dim Question_responseP1, Question_responseP2 As Integer
  Dim Player_Total_ScoreP1, Player_Total_ScoreP2, Player_Total_Speed As Integer
  Dim start_of_trial, start_of_option, prev_trial_time, delay As Double
  Dim alt As Integer
  Dim ans, missed_ans, x_t_1, y_t_1, x_t_2, y_t_2, x_t_3, y_t_3, x_t_4, y_t_4 As Integer
  Dim numquest As Integer ' this is the total number of questions in the game,questions per slide, slide
number
  Dim cfg_data(200), questions(100, 20), questions_na(100, 20) As String
  Dim x_lo_lim, x_hi_lim, y_lo_lim, y_hi_lim, DISP_I, TRAV_I, X_sights, Y_line, X_sights1, Y_line1 As Integer
  Dim SelectOrder(100), screen_order(4), colour_order(4), trial_order(5), action, no_action, NAns, PossAns,
disp_interval, rpt_q, block, First_miss As Integer
  Dim loc_x_1, loc_y_1, loc_x_2, loc_y_2, loc_x_3, loc_y_3, loc_x_4, loc_y_4 As Integer
  Dim cloud_x_1, cloud_y_1, cloud_x_2, cloud_y_2, cloud_x_3, cloud_y_3
  Dim strcfg, strquest, strquest_na, strpoints, L_R As String
  Dim MyRandom As New Random
  Dim Trajectory(12, 2) As Integer
  Dim X_trajectory, Y_trajectory, Traj, Trajx(4), shoot, press_fire As Integer
  Dim x_min, x_max, box_x, box_y, act_or_not, TRAV1_INT As Integer
  Dim point1, point2, point3, point4, point5, point6, point7 As Point
  ' unwanted variables Dim x_t, y_t, Opt, cor_incor, loc_x, loc_y, test, slide, Player_Turn_Score  as integer
  Dim x_corr, y_corr, rot, corr_butt(4), incorr_butt(4), num_ints As Integer
  Dim action_time_on_screen, na_time_on_screen As Double
  Dim WithEvents Player As System.Windows.Forms.TextBox
  Public Sub form1_loadquest(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
MyBase.Load
    x_corr = 75
    y_corr = 55 ' correction for not anchoring picture of explosion at centre!
    rot = 1
    ' alt = 0
    'Trajectory(1, 1) = 0
    ' Trajectory(1, 2) = 5
    Trajectory(2, 1) = 4
    Trajectory(2, 2) = 1
```

```
Trajectory(3, 1) = 3
Trajectory(3, 2) = 4
Trajectory(4, 1) = 0
Trajectory(4, 2) = 5
Trajectory(5, 1) = 1
Trajectory(5, 2) = 4
Trajectory(1, 1) = 4
Trajectory(1, 2) = 3
box_x = 70 ' size of ButtOpt (width)
box_y = 70 'size of ButtOpt (height)
But1_P1.Size = New Point(5, box_y)
But1_P2.Size = New Point(5, box_y)
But2_P1.Size = New Point(5, box_y)
But2_P2.Size = New Point(5, box_y)
But3_P1.Size = New Point(5, box_y)
But3_P2.Size = New Point(5, box_y)
But4_P1.Size = New Point(5, box_y)
But4_P2.Size = New Point(5, box_y)
ButtOpt1.Size = New Point(box_x, box_y)
ButtOpt2.Size = New Point(box_x, box_y)
ButtOpt3.Size = New Point(box_x, box_y)
ButtOpt4.Size = New Point(box_x, box_y)

x_min = 10
x_max = 980
X_sights = 480
Y_line = 300
X_sights1 = 500
Y_line1 = 300
LineShape1.StartPoint = New Point(10, Y_line)
LineShape1.EndPoint = New Point(980, Y_line)
LineShape2.StartPoint = New Point(X_sights, Y_line)
LineShape2.EndPoint = New Point(X_sights, Y_line)
LineShape3.StartPoint = New Point(X_sights1, Y_line1)
LineShape3.EndPoint = New Point(X_sights1, Y_line1)
Label1.Visible = False
Label2.Visible = False
Label3.Visible = False
Label4.Visible = False
Label5.Visible = False
Label6.Visible = False

lblMessage.Location = New Point(150, 200)
lblMessage.Size = New Point(666, 160)
lblMessage.Text = "SHOOT THE PRIME!"
lblMessage.Visible = True

For n = 6 To 10
   Trajectory(n, 1) = -Trajectory(n - 5, 1)
   Trajectory(n, 2) = -Trajectory(n - 5, 2)
Next n
' lblMessage.Text = Trajectory(8, 1) & " " & Trajectory(8, 2)
'cfg file:
'01:home directory for files
'02:question file name
```

```
    '03:learning content directory name
    '06:data file name
    '07:number of questions (should correspond with size of 02,03 and 05)
    '08:=1 if Active gaming
    '10:ITI_Timer.Interval = time before the ITI = Gaming Feedback Time
    '11:Start_Trial_Timer.Interval = time before Trial starts = ITI ENDS - BIOPAC Digital Ch 1 Event starts =
Learning presented
    '14:Trial_Timer.Interval = time before trial ends
    '20:number of correct answers
    '21:number of times to repeat questions
    '22:Option Interval
    '23:Travel Interval
    '25: = question file name for no action
    disp_interval = 10000
    TRAV1_INT = 30
    '  Trav1.Interval = 100
    x_lo_lim = 50
    x_hi_lim = 700
    y_lo_lim = 50
    y_hi_lim = 450
    'ActionBox.Location = New Point(x_lo_lim, y_lo_lim)
    'ActionBox.Width = x_hi_lim - x_lo_lim + 68 ' 68 is width of box
    'ActionBox.Height = y_hi_lim - y_lo_lim + 38 ' 38 is height of box
  End Sub
```

```
  Public Sub ArrangeQuestionOrder()
    ' SelectOrder will contain the randomised order of questions presented
    For Me.block = 1 To rpt_q
      SelectOrder(1 + (block - 1) * numquest) = MyRandom.Next(numquest) + 1
      For N = 2 To numquest
        candidate = MyRandom.Next(numquest) + 1
        taken = 0
        For SO = 1 To N - 1
          If SelectOrder(SO + (block - 1) * numquest) = candidate Then taken = 1
        Next
        If taken = 0 Then
          SelectOrder(N + (block - 1) * numquest) = candidate
        Else : N = N - 1
        End If
      Next
    Next
    numquest = numquest * rpt_q
  End Sub
```

```
  Public Sub ArrangeScreenOrder()
    ' Screen_Order will contain the randomised order of questions presented in the boxes
    screen_order(1) = MyRandom.Next(4) + 1
    For N = 2 To 4
      candidate = MyRandom.Next(4) + 1
      taken = 0
      For SO = 1 To N - 1
        If screen_order(SO) = candidate Then taken = 1
      Next
      If taken = 0 Then
        screen_order(N) = candidate
      Else : N = N - 1
      End If
```

```vb
    Next
End Sub
```

```vb
Public Sub ArrangeColourOrder()
    'Colour_Order will contain the randomised order of colours presented in the boxes
    colour_order(1) = MyRandom.Next(4) + 1
    For N = 2 To 4
        candidate = MyRandom.Next(4) + 1
        taken = 0
        For SO = 1 To N - 1
            If colour_order(SO) = candidate Then taken = 1
        Next
        If taken = 0 Then
            colour_order(N) = candidate
        Else : N = N - 1
        End If
    Next
End Sub
```

```vb
Public Sub btnNew_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
btnNew.Click
    Dim cfgfile As New System.IO.StreamReader(cfgbox.Text + ".txt")
    Dim lengt, cfg As Integer
    ' lblMessage.Text = CStr(disp_interval) & "   " & CStr(Trav1.Interval)
    btnNew.BackColor = Color.WhiteSmoke
    act_or_not = 1
    ' If act_or_not = 1 Then act_or_not = 0 Else act_or_not = 1
    'quest = 0
    lblMessage.Visible = False
    strcfg = cfgfile.ReadLine()
    Do Until strcfg Is Nothing
        For cfg = 1 To 25 ' 21 because that takes strcfg to nothing
            cfg_data(cfg) = strcfg
            strcfg = cfgfile.ReadLine()
            lengt = Microsoft.VisualBasic.Len(cfg_data(cfg))
            If lengt > 3 Then cfg_data(cfg) = Microsoft.VisualBasic.Right(cfg_data(cfg), lengt - 3)
        Next
    Loop
    cfgfile.Close()
    cfgfile.Dispose()
    numquest = cfg_data(7)
    action = cfg_data(8) 'do question move?
    ITI_Timer.Interval = Int(cfg_data(10)) 'Inter-trial interval
    Start_Trial_Timer.Interval = cfg_data(11) ' Time for learning before question - that's zero in your study?
    Trial_Timer.Interval = cfg_data(14) ' how long the question lasts for
    NAns = cfg_data(20) ' number of times that the correct answer appears
    rpt_q = cfg_data(21) ' number of times that question gets repeated
    DISP_I = cfg_data(22) 'increment by which duration of the display of option is being
increased/decreased - decides how rapidly options are appearing/disappearing
    TRAV_I = cfg_data(23) 'increment by which delay before moving to next position is being
increased/decreased
    ' test = cfg_data(24)
    'no_action = cfg_data(25) 'static trial corpus

    If action = 1 Then
        Trav1.Enabled = True 'starts Trav1 is the timer for the answer travelling. Every time it goes off, the
answer moves.
```

```
            Selector.Visible = False
        End If

        read_questions() ' goes to a routine that loads up the questions into questions(quest, N) where quest is
question number e.g. Q7 and if N = 0, its the question 7, N=1 it's option 1 for question 7 etc
        read_questions_noaction()
        ArrangeQuestionOrder() ' produces a random sequence of integers (in SelectOrder) from 1 to
NumQuest, for randomising selection of questions
        ArrangeScreenOrder()

        Taking_Answers = 0 ' this means that its not presently possible to enter an answer
        Player_Total_ScoreP1 = 0 ' set player score to 0
        Player_Total_ScoreP2 = 0 'set player 2 score to 0
        Player_Total_Speed = 0
        Player_score_display.Text = Player_Total_ScoreP1 ' display the player's score
        Player_score_display2.Text = Player_Total_ScoreP2 ' display the player 2's score
        Player_Speed_dial.Text = Player_Total_Speed 'display the player's speed based on adaptive
disp_interval
        'Out(&HE050S, &H0S) ' all EVENTs at zero

        ' Below writes an introductory line on data file - includes DOB etc
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), vbNewLine & "NEW
PARTICIPANTS" & " " & DOB_P1.Text & " " & DOB_P2.Text & " " & cfgbox.Text, True)
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), vbNewLine, True)
        startTime = Now ' store the start time of the game
        run_game()
        cfgbox.Visible = False
        DOB_P1.Visible = False
        DOB_P2.Visible = False
        btnNew.Visible = False

    End Sub
```

```
    Public Sub run_game()
        eventTime = Now ' COLUMN 1 = start of learn
        Trial_Timer.Start()
        Timer1.Enabled = True
        clock.Width = 5
        press_fire = 0
        If quest_num = numquest Then
            ITI_Timer.Enabled = False ' since end of game, switch off countdown to next trial
            endgame()
        Else 'not end of game so set up game to start....
            Prepare_for_next_question()
            start_of_trial = eventTime.Subtract(startTime).TotalSeconds
            Start_Trial_Timer.Enabled = True
            press_fire = 0
            quest = SelectOrder(quest_num)
            'ActionBox.Visible = False
        End If
    End Sub
```

```
    Private Sub ITI_Timer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
ITI_Timer.Tick
        ITI_Timer.Enabled = False
        'ActionBox.Image = Nothing
        run_game()
```

```vb
    End Sub
    Private Sub Start_Trial_Timer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Start_Trial_Timer.Tick
        eventTime = Now         'Out(&HE050S, &H1S) ' EVENT 1 Starts
        startTrial = Now
        If act_or_not = 1 Then act_or_not = 0 Else act_or_not = 1
        If act_or_not = 1 Then Trav1.Interval = TRAV1_INT
        If act_or_not = 0 Then Trav1.Interval = 50000
        Start_Trial_Timer.Enabled = False
        Trial_Timer.Enabled = True
        Question_responded_P1 = 0
        Question_responded_P2 = 0
        Question.Text = questions(quest, 0) ' + " " + Str(quest)

        If act_or_not = 1 Then
            ButtOpt1.Text = questions(quest, 1)
            ButtOpt2.Text = questions(quest, 2)
            ButtOpt3.Text = questions(quest, 3)
            ButtOpt4.Text = questions(quest, 4)

        Else
            ArrangeScreenOrder()

            ButtOpt1.Text = questions_na(quest, screen_order(1))
            ButtOpt2.Text = questions_na(quest, screen_order(2))
            ButtOpt3.Text = questions_na(quest, screen_order(3))
            ButtOpt4.Text = questions_na(quest, screen_order(4))
        End If

        GameProgress.Text = "Q:" + Str(quest_num)
        Taking_Answers = 1
        ans = 0
        start_of_trial = eventTime.Subtract(startTime).TotalSeconds
        PlayWackerMole()
    End Sub
```

```vb
    Public Sub ran_loc_and_opt()
        eventTime = Now
        If act_or_not = 1 Then loc_x_1 = MyRandom.Next(x_lo_lim, x_hi_lim)
        If act_or_not = 1 Then loc_y_1 = MyRandom.Next(y_lo_lim, y_hi_lim)
        If act_or_not = 1 Then loc_x_2 = MyRandom.Next(x_lo_lim, x_hi_lim)
        If act_or_not = 1 Then loc_y_2 = MyRandom.Next(y_lo_lim, y_hi_lim)
        If act_or_not = 1 Then loc_x_3 = MyRandom.Next(x_lo_lim, x_hi_lim)
        If act_or_not = 1 Then loc_y_3 = MyRandom.Next(y_lo_lim, y_hi_lim)
        If act_or_not = 1 Then loc_x_4 = MyRandom.Next(x_lo_lim, x_hi_lim)
        If act_or_not = 1 Then loc_y_4 = MyRandom.Next(y_lo_lim, y_hi_lim)

        LineShape1.Visible = True
        LineShape2.Visible = True
        LineShape3.Visible = True
        LineShape2.StartPoint = New Point(X_sights, Y_line - 20)
        LineShape2.EndPoint = New Point(X_sights, Y_line + 20)
        LineShape3.StartPoint = New Point(X_sights1, Y_line1 - 20)
        LineShape3.EndPoint = New Point(X_sights1, Y_line1 + 20)
        Label1.Visible = True
        Label2.Visible = True
```

```vb
        Label3.Visible = True
        Label4.Visible = False
        Label5.Visible = False
        Label6.Visible = False

        ButtOpt1.BackColor = Color.Black
        ButtOpt2.BackColor = Color.Black
        ButtOpt3.BackColor = Color.Black
        ButtOpt4.BackColor = Color.Black

        If act_or_not = 0 Then
            loc_x_1 = 158
            loc_y_1 = 171
            loc_x_2 = 736
            loc_y_2 = 171
            loc_x_3 = 158
            loc_y_3 = 402
            loc_x_4 = 736
            loc_y_4 = 402
            LineShape1.Visible = False
            LineShape2.Visible = False
            LineShape3.Visible = False

            ButtOpt1.BackColor = Color.Black
            ButtOpt2.BackColor = Color.Black
            ButtOpt3.BackColor = Color.Black
            ButtOpt4.BackColor = Color.Black
            But1_P1.BackColor = Color.White
            But1_P2.BackColor = Color.White
            'But2_P1.BackColor = Color.White
            'But2_P2.BackColor = Color.White
            'But3_P1.BackColor = Color.White
            'But3_P2.BackColor = Color.White
            'But4_P1.BackColor = Color.White
            'But4_P2.BackColor = Color.White

            Label1.Visible = False
            Label2.Visible = False
            Label3.Visible = False
            Label4.Visible = True
            Label5.Visible = True
            Label6.Visible = True

        End If

        eventTime = Now
        start_of_option = eventTime.Subtract(startTime).TotalSeconds
        Question_responded_P1 = 0
        Question_responded_P2 = 0

    End Sub
```

```vb
    Public Sub PlayWackerMole()
        X_sights = 480
        X_sights1 = 500
        ArrangeColourOrder()
```

```
set_colourP1()
set_colourP2()
ran_loc_and_opt()

Trajx(1) = MyRandom.Next(1, 10) ' to avoid overlapping of trajectories
For N = 2 To 4
  candidate = MyRandom.Next(1, 10)
  taken = 0
  For X = 1 To N - 1
    If Trajx(X) = candidate Then taken = 1
  Next
  If taken = 0 Then
    Trajx(N) = candidate
  Else : N = N - 1
  End If
Next
'lblMessage.Text = Trajx(1) & " " & Trajx(2) & " " & Trajx(3) & " " & Trajx(4) & " "

'Traj = MyRandom.Next(1, 13)
x_t_1 = Trajectory(Trajx(1), 1)
y_t_1 = Trajectory(Trajx(1), 2)
'Traj = MyRandom.Next(1, 13)
x_t_2 = Trajectory(Trajx(2), 1)
y_t_2 = Trajectory(Trajx(2), 2)
'Traj = MyRandom.Next(1, 13)
x_t_3 = Trajectory(Trajx(3), 1)
y_t_3 = Trajectory(Trajx(3), 2)
'Traj = MyRandom.Next(1, 13)
x_t_4 = Trajectory(Trajx(4), 1)
y_t_4 = Trajectory(Trajx(4), 2)

ButtOpt1.Visible = True
ButtOpt2.Visible = True
ButtOpt3.Visible = True
ButtOpt4.Visible = True
But1_P1.Visible = True
But1_P2.Visible = True
But2_P1.Visible = True
But2_P2.Visible = True
But3_P1.Visible = True
But3_P2.Visible = True
But4_P1.Visible = True
But4_P2.Visible = True

ButtOpt1.Location = New Point(loc_x_1, loc_y_1)
ButtOpt2.Location = New Point(loc_x_2, loc_y_2)
ButtOpt3.Location = New Point(loc_x_3, loc_y_3)
ButtOpt4.Location = New Point(loc_x_4, loc_y_4)
But1_P1.Location = New Point(loc_x_1 - 5, loc_y_1)
But1_P2.Location = New Point(loc_x_1 + 65, loc_y_1)
But2_P1.Location = New Point(loc_x_2 - 5, loc_y_2)
But2_P2.Location = New Point(loc_x_2 + 65, loc_y_2)
But3_P1.Location = New Point(loc_x_3 - 5, loc_y_3)
But3_P2.Location = New Point(loc_x_3 + 65, loc_y_3)
But4_P1.Location = New Point(loc_x_4 - 5, loc_y_4)
```

```
        But4_P2.Location = New Point(loc_x_4 + 65, loc_y_4)

        First_miss = 0

    End Sub
```

```
    Private Sub Trav1_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles Trav1.Tick
'makes the option buttons move
        ' 1
        loc_x_1 = loc_x_1 + (x_t_1)
        loc_y_1 = loc_y_1 + (y_t_1)
        If (loc_x_1 < x_lo_lim) Or (loc_x_1 > x_hi_lim) Then x_t_1 = -x_t_1
        If (loc_y_1 < y_lo_lim) Or (loc_y_1 > y_hi_lim) Then y_t_1 = -y_t_1
        ButtOpt1.Location = New Point(loc_x_1, loc_y_1) 'ButOpt1,2,3,4 are the option buttons you press to
indicate choice
        ButtOpt2.Location = New Point(loc_x_2, loc_y_2)
        ButtOpt3.Location = New Point(loc_x_3, loc_y_3)
        ButtOpt4.Location = New Point(loc_x_4, loc_y_4)
        ' 2
        loc_x_2 = loc_x_2 + (x_t_2)
        loc_y_2 = loc_y_2 + (y_t_2)
        If (loc_x_2 < x_lo_lim) Or (loc_x_2 > x_hi_lim) Then x_t_2 = -x_t_2
        If (loc_y_2 < y_lo_lim) Or (loc_y_2 > y_hi_lim) Then y_t_2 = -y_t_2
        ButtOpt1.Location = New Point(loc_x_1, loc_y_1) 'ButOpt1,2,3,4 are the option buttons you press to
indicate choice
        ButtOpt2.Location = New Point(loc_x_2, loc_y_2)
        ButtOpt3.Location = New Point(loc_x_3, loc_y_3)
        ButtOpt4.Location = New Point(loc_x_4, loc_y_4)
        '3
        loc_x_3 = loc_x_3 + (x_t_3)
        loc_y_3 = loc_y_3 + (y_t_3)
        If (loc_x_3 < x_lo_lim) Or (loc_x_3 > x_hi_lim) Then x_t_3 = -x_t_3
        If (loc_y_3 < y_lo_lim) Or (loc_y_3 > y_hi_lim) Then y_t_3 = -y_t_3
        ButtOpt1.Location = New Point(loc_x_1, loc_y_1) 'ButOpt1,2,3,4 are the option buttons you press to
indicate choice
        ButtOpt2.Location = New Point(loc_x_2, loc_y_2)
        ButtOpt3.Location = New Point(loc_x_3, loc_y_3)
        ButtOpt4.Location = New Point(loc_x_4, loc_y_4)
        '4
        loc_x_4 = loc_x_4 + (x_t_4)
        loc_y_4 = loc_y_4 + (y_t_4)
        If (loc_x_4 < x_lo_lim) Or (loc_x_4 > x_hi_lim) Then x_t_4 = -x_t_4
        If (loc_y_4 < y_lo_lim) Or (loc_y_4 > y_hi_lim) Then y_t_4 = -y_t_4
        ButtOpt1.Location = New Point(loc_x_1, loc_y_1) 'ButOpt1,2,3,4 are the option buttons you press to
indicate choice
        ButtOpt2.Location = New Point(loc_x_2, loc_y_2)
        ButtOpt3.Location = New Point(loc_x_3, loc_y_3)
        ButtOpt4.Location = New Point(loc_x_4, loc_y_4)

        But1_P1.Visible = False
        But1_P2.Visible = False
        But2_P1.Visible = False
        But2_P2.Visible = False
        But3_P1.Visible = False
        But3_P2.Visible = False
        But4_P1.Visible = False
```

```
        But4_P2.Visible = False

    End Sub
```

```
    Private Sub Trial_Timer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Trial_Timer.Tick
        Timer1.Enabled = True
        Trial_ends()
    End Sub
```

```
    Public Sub Trial_ends()
        eventTime = Now      ' Out(&HE050S, &H10S) ' EVENT 3,4 ends, 5 Starts
        If Question_responded_P1 = 0 And Question_responded_P2 = 0 Then mark_timeout()
        'mark_timeoutP2()
        WellDone.Visible = False
        IntOptPause_Timer.Enabled = False
        Trial_Timer.Enabled = False
        Timer1.Enabled = False
        ITI_Timer.Enabled = True
        Taking_Answers = 0
        Explosion.Visible = False

    End Sub
```

```
    Public Sub ActionFeedbackP1()
        ActionFeedbackTimer.Enabled = True
        ' time stamp
        screenTime = Now
        'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), eventTime & " " &
screenTime & " ", True)
        'If Question_responded_P1 = 1 And Question_responded_P2 = 0 Then
My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
screenTime.Subtract(startTrial).TotalSeconds & " ", True)
        'If Question_responded_P1 = 0 And Question_responded_P2 = 1 Then
My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
screenTime.Subtract(startTrial).TotalSeconds & " ", True)
        'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), vbNewLine, True)

        'If test = 0 Then To use the same game as tester but with the static form - possibility discarded
        'If ans = 1 Then
        'WellDone.BackColor = Color.FromArgb(98, 196, 81)
        'WellDone.Visible = True

        'If act_or_not = 1 Then
        'WellDone.Text = questions(quest, 4 + NAns + Question_response)
        'Else
        'WellDone.Text = questions_na(quest, 4 + NAns + Question_response)
        'End If

        Player_score_display.Text = Player_Total_ScoreP1
        'Player_Speed_dial.Text = Player_Total_Speed
        'End If
        'End If
        'If test = 0 Then
        'If ans = 0 Then
        'WellDone.BackColor = Color.Red
        'WellDone.Visible = True
        'If act_or_not = 1 Then
```

```
            'WellDone.Text = questions(quest, 4 + NAns + Question_response)
            'Else
            'WellDone.Text = questions_na(quest, 4 + NAns + Question_response)
            'End If
            'End If

    End Sub
```

```
    Public Sub ActionFeedbackP2()
        ActionFeedbackTimer.Enabled = True
        ' time stamp
        screenTime = Now
        'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), eventTime & " " &
screenTime & " ", True)
        'If Question_responded_P2 = 1 And Question_responded_P1 = 0 Then
My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
screenTime.Subtract(startTrial).TotalSeconds & " ", True)
        'If Question_responded_P2 = 0 And Question_responded_P1 = 1 Then
My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
screenTime.Subtract(startTrial).TotalSeconds & " ", True)
        'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), vbNewLine, True)

        'If test = 0 Then To use the same game as tester but with the static form - possibility discarded
        'If ans = 1 Then
        'WellDone.BackColor = Color.FromArgb(98, 196, 81)
        'WellDone.Visible = True

        'If act_or_not = 1 Then
        'WellDone.Text = questions(quest, 4 + NAns + Question_response)
        'Else
        'WellDone.Text = questions_na(quest, 4 + NAns + Question_response)
        'End If

        Player_score_display2.Text = Player_Total_ScoreP2
        'Player_Speed_dial.Text = Player_Total_Speed
        'End If
        'End If
        'If test = 0 Then
        'If ans = 0 Then
        'WellDone.BackColor = Color.Red
        'WellDone.Visible = True
        'If act_or_not = 1 Then
        'WellDone.Text = questions(quest, 4 + NAns + Question_response)
        'Else
        'WellDone.Text = questions_na(quest, 4 + NAns + Question_response)
        'End If
        'End If

    End Sub
```

```
    Public Sub Prepare_for_next_question()
        quest_num = quest_num + 1
        Points_available.Text = 10
        Points_available.ForeColor = Color.White
        Question_responseP1 = 0
        Question_responseP2 = 0
        Taking_Answers = 0
```

```
        ' Player_Turn_Score = 0
        Player_score_display.BackColor = Color.Gray
        Player_score_display.ForeColor = Color.White
        Player_score_display2.BackColor = Color.Gray
        Player_score_display2.ForeColor = Color.White
        Trav1.Enabled = True
        clock.Visible = True

    End Sub
    Private Sub Stop_Button_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Stop_Button.Click
        Me.Close()
    End Sub
    Public Sub record_question_response()
        eventTime = Now ' If competitor_taking_answers = 1 Then Out(&HE050S, &H8S) Else Out(&HE050S,
&HCS) ' EVENT 3 ends continues, 4 Starts

        If act_or_not = 1 Then
            action_time_on_screen = action_time_on_screen + eventTime.Subtract(startTrial).TotalSeconds
        Else
            na_time_on_screen = na_time_on_screen + eventTime.Subtract(startTrial).TotalSeconds
        End If

        'If act_or_not = 1 Then
        'If quest_num > 1 Then
        'If time_on_screen.Second > screenTime.Subtract(eventTime).TotalSeconds Then
        'If prev_trial_time < eventTime.Subtract(startTrial).TotalSeconds Then

        If act_or_not = 0 Then
            If na_time_on_screen < action_time_on_screen Then
                Feedback_delay.Interval = (action_time_on_screen - na_time_on_screen) * 1000
                na_time_on_screen = na_time_on_screen + Feedback_delay.Interval / 1000
            Else
                If na_time_on_screen > action_time_on_screen Then
                    na_time_on_screen = na_time_on_screen + 1 / 1000
                    Feedback_delay.Interval = 1
                End If
            End If
        End If

        ' If act_or_not = 1 Then
        'If na_time_on_screen > action_time_on_screen Then
        'Feedback_delay.Interval = (na_time_on_screen - action_time_on_screen) * 1000
        'End If
        'End If
        'End If
        'prev_trial_time = eventTime.Subtract(startTrial).TotalSeconds

        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
eventTime.Subtract(startTime).TotalSeconds & " ", True)

        If Question_responded_P1 = 0 And Question_responded_P2 = 1 Then
My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "P1_0" & " ", True)
        If Question_responded_P2 = 0 And Question_responded_P1 = 1 Then
My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "P2_0" & " ", True)
```

```
        If Question_responded_P1 = 0 And Question_responded_P2 = 0 Then
My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "P1_0-P2_0" & " ", True)

        If Question_responded_P1 = 1 Then My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" +
cfg_data(6) + ".txt"), eventTime.Subtract(startTrial).TotalSeconds & " ", True)
        If Question_responded_P2 = 1 Then My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" +
cfg_data(6) + ".txt"), eventTime.Subtract(startTrial).TotalSeconds & " ", True)
        If Question_responded_P1 = 0 And Question_responded_P2 = 0 Then
My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
eventTime.Subtract(startTrial).TotalSeconds & " ", True)

        'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
eventTime.Subtract(startTime).TotalSeconds & " ", True)
        'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
Feedback_delay.Interval & " ", True)
        'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
action_time_on_screen & " ", True)
        'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), na_time_on_screen &
" ", True)

        If act_or_not = 0 Then
            My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "No_Action" & " ",
True)
        Else
            My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "Action" & " ", True)
        End If
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), vbNewLine, True)

        'time_on_screen = Date.FromOADate(screenTime.Subtract(eventTime).TotalSeconds)

    End Sub
```

```
    Public Sub read_questions()
        Dim objfile As New System.IO.StreamReader(cfg_data(1) + "\" + cfg_data(2) + ".txt")
        strquest = objfile.ReadLine()
        quest = 0
        Do Until strquest Is Nothing
            quest = quest + 1
            For N = 0 To 4 + NAns + 4
                questions(quest, N) = strquest
                strquest = objfile.ReadLine()
            Next
        Loop
    End Sub
```

```
    Public Sub read_questions_noaction()
        Dim objfile As New System.IO.StreamReader(cfg_data(1) + "\" + cfg_data(2) + "_na" + ".txt")
        strquest = objfile.ReadLine()
        quest = 0
        Do Until strquest Is Nothing
            quest = quest + 1
            For N = 0 To 4 + NAns + 4
                questions_na(quest, N) = strquest
                strquest = objfile.ReadLine()
            Next
        Loop
    End Sub
```

```
Public Sub endgame()
    btnNew.BackColor = Color.Red
    Player_score_display.BackColor = Color.Yellow
    Player_score_display.ForeColor = Color.Firebrick
    Player_score_display2.BackColor = Color.Aqua
    Player_score_display2.ForeColor = Color.Firebrick
    lblMessage.Visible = True
    lblMessage.Location = New Point(150, 200)
    lblMessage.Size = New Point(666, 160)
    lblMessage.Text = "GAME OVER"
    ButtOpt1.Visible = False
    ButtOpt2.Visible = False
    ButtOpt3.Visible = False
    ButtOpt4.Visible = False

    But1_P1.Visible = False
    But1_P2.Visible = False
    But2_P1.Visible = False
    But2_P2.Visible = False
    But3_P1.Visible = False
    But3_P2.Visible = False
    But4_P1.Visible = False
    But4_P2.Visible = False

    clock.Visible = False

End Sub
```

```
Private Sub mark_hitP1()
    ans = 0
    For Me.PossAns = 1 To NAns
        If Question_responseP1 = questions(quest, 5) Then
            ans = 1
            Player_Total_ScoreP1 = Player_Total_ScoreP1 + 10
            Player_score_display.BackColor = Color.Red
            Player_score_display.BackColor = Color.Gray
            'Player_Total_Speed = (200000 / disp_interval)
            'Player_Speed_dial.Text = Player_Total_Speed
            Player_score_display.Text = CStr(Player_Total_ScoreP1)
        End If

        If act_or_not = 1 Then
            If ans = 1 Then
                If Question_responseP1 = 1 Then ButtOpt1.BackColor = Color.FromArgb(0, 109, 40)
                If Question_responseP1 = 2 Then ButtOpt2.BackColor = Color.FromArgb(0, 109, 40)
                If Question_responseP1 = 3 Then ButtOpt3.BackColor = Color.FromArgb(0, 109, 40)
                If Question_responseP1 = 4 Then ButtOpt4.BackColor = Color.FromArgb(0, 109, 40)
                'lblMessage.Text = quest & " " & questions(quest, 5)
                WellDone.Visible = True
                WellDone.Text = "Next trial coming..."
            End If

            If ans = 0 Then
                If Question_responseP1 = 1 Then ButtOpt1.BackColor = Color.FromArgb(186, 26, 19)
                If Question_responseP1 = 2 Then ButtOpt2.BackColor = Color.FromArgb(186, 26, 19)
                If Question_responseP1 = 3 Then ButtOpt3.BackColor = Color.FromArgb(186, 26, 19)
```

```
                If Question_responseP1 = 4 Then ButtOpt4.BackColor = Color.FromArgb(186, 26, 19)
                'lblMessage.Text = quest & " " & questions(quest, 5)
                WellDone.Visible = True
                WellDone.Text = "Next trial coming..."
            End If
        End If

        If act_or_not = 0 Then
            set_colourP1()
            If ans = 1 Then
                If Question_responseP1 = screen_order(1) Then ButtOpt1.BackColor = Color.FromArgb(0, 109,
40)
                If Question_responseP1 = screen_order(2) Then ButtOpt2.BackColor = Color.FromArgb(0, 109,
40)
                If Question_responseP1 = screen_order(3) Then ButtOpt3.BackColor = Color.FromArgb(0, 109,
40)
                If Question_responseP1 = screen_order(4) Then ButtOpt4.BackColor = Color.FromArgb(0, 109,
40)
                'lblMessage.Text = quest & " " & questions(quest, 5)
                WellDone.Visible = True
                WellDone.Text = "Next trial coming..."
            End If

            If ans = 0 Then
                If Question_responseP1 = screen_order(1) Then ButtOpt1.BackColor = Color.FromArgb(186, 26,
19)
                If Question_responseP1 = screen_order(2) Then ButtOpt2.BackColor = Color.FromArgb(186, 26,
19)
                If Question_responseP1 = screen_order(3) Then ButtOpt3.BackColor = Color.FromArgb(186, 26,
19)
                If Question_responseP1 = screen_order(4) Then ButtOpt4.BackColor = Color.FromArgb(186, 26,
19)
                'lblMessage.Text = quest & " " & questions(quest, 5)
                WellDone.Visible = True
                WellDone.Text = "Next trial coming..."
            End If
        End If

    Next PossAns
    Question_responded_P1 = 1
    If ans = 1 Then
        record_start_of_data_line()
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "P1" & " ", True)
'Records type of player in primer_data file
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "Correct" & " ", True)
'Records type of answer in primer_data file
    End If
    If ans = 0 Then
        record_start_of_data_line()
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "P1" & " ", True)
'Records type of player in primer_data file
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "Incorrect" & " ",
True)
    End If
    record_question_response()
```

```
        Taking_Answers = 0
        clock.Visible = False

    End Sub
```

```
    Private Sub mark_hitP2()
        ans = 0
        For Me.PossAns = 1 To NAns
            If Question_responseP2 = questions(quest, 5) Then
                ans = 1
                Player_Total_ScoreP2 = Player_Total_ScoreP2 + 10
                Player_score_display2.BackColor = Color.Red
                Player_score_display2.BackColor = Color.Gray
                'Player_Total_Speed = (200000 / disp_interval)
                'Player_Speed_dial.Text = Player_Total_Speed
                Player_score_display2.Text = CStr(Player_Total_ScoreP2)
            End If

            If act_or_not = 1 Then
                If ans = 1 Then
                    If Question_responseP2 = 1 Then ButtOpt1.BackColor = Color.FromArgb(0, 109, 40)
                    If Question_responseP2 = 2 Then ButtOpt2.BackColor = Color.FromArgb(0, 109, 40)
                    If Question_responseP2 = 3 Then ButtOpt3.BackColor = Color.FromArgb(0, 109, 40)
                    If Question_responseP2 = 4 Then ButtOpt4.BackColor = Color.FromArgb(0, 109, 40)
                    'lblMessage.Text = quest & " " & questions(quest, 5)
                    WellDone.Visible = True
                    WellDone.Text = "Next trial coming..."
                End If

                If ans = 0 Then
                    If Question_responseP2 = 1 Then ButtOpt1.BackColor = Color.FromArgb(186, 26, 19)
                    If Question_responseP2 = 2 Then ButtOpt2.BackColor = Color.FromArgb(186, 26, 19)
                    If Question_responseP2 = 3 Then ButtOpt3.BackColor = Color.FromArgb(186, 26, 19)
                    If Question_responseP2 = 4 Then ButtOpt4.BackColor = Color.FromArgb(186, 26, 19)
                    'lblMessage.Text = quest & " " & questions(quest, 5)
                    WellDone.Visible = True
                    WellDone.Text = "Next trial coming..."
                End If
            End If

            If act_or_not = 0 Then
                set_colourP2()
                If ans = 1 Then
                    If Question_responseP2 = screen_order(1) Then ButtOpt1.BackColor = Color.FromArgb(0, 109,
40)
                    If Question_responseP2 = screen_order(2) Then ButtOpt2.BackColor = Color.FromArgb(0, 109,
40)
                    If Question_responseP2 = screen_order(3) Then ButtOpt3.BackColor = Color.FromArgb(0, 109,
40)
                    If Question_responseP2 = screen_order(4) Then ButtOpt4.BackColor = Color.FromArgb(0, 109,
40)
                    'lblMessage.Text = quest & " " & questions(quest, 5)
                    WellDone.Visible = True
                    WellDone.Text = "Next trial coming..."
                End If
```

```
            If ans = 0 Then
              If Question_responseP2 = screen_order(1) Then ButtOpt1.BackColor = Color.FromArgb(186, 26,
19)
              If Question_responseP2 = screen_order(2) Then ButtOpt2.BackColor = Color.FromArgb(186, 26,
19)
              If Question_responseP2 = screen_order(3) Then ButtOpt3.BackColor = Color.FromArgb(186, 26,
19)
              If Question_responseP2 = screen_order(4) Then ButtOpt4.BackColor = Color.FromArgb(186, 26,
19)
              'lblMessage.Text = quest & " " & questions(quest, 5)
              WellDone.Visible = True
              WellDone.Text = "Next trial coming..."
            End If

          End If

        Next PossAns
        Question_responded_P2 = 1
        If ans = 1 Then
          record_start_of_data_line()
          My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "P2" & " ", True)
'Records type of player in primer_data file
          My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "Correct" & " ", True)
'Records type of answer in primer_data file
        End If
        If ans = 0 Then
          record_start_of_data_line()
          My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "P2" & " ", True)
'Records type of player in primer_data file
          My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "Incorrect" & " ",
True)
        End If
        record_question_response()
        Taking_Answers = 0
        clock.Visible = False
    End Sub
```

```
    Private Sub mark_timeout()
        'Records when question is not responded as Time_out in primer_data file
        'If Question_responded_P1 = 1 Then Question_responded_P2 = 0
        'If Question_responded_P1 = 0 Then Question_responded_P2 = 1
        If Question_responded_P1 = 0 And Question_responded_P2 = 0 Then
          record_start_of_data_line()
          My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "P1-P2" & " ", True)
          My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "Time_out" & " ",
True)
        End If
        record_question_response()
        Taking_Answers = 0
        'End If
    End Sub
```

```
    Private Sub ActionFeedbackTimer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles ActionFeedbackTimer.Tick
        ActionFeedbackTimer.Enabled = False
        Trial_ends()
    End Sub
```

```
    Private Sub WellDone_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
WellDone.Click

    End Sub
```

```
    Private Sub ExplodeP1()
        If act_or_not = 1 Then
            If Question_responseP1 = 1 Then
                Trav1.Enabled = False
                Label1.Visible = False
                Label2.Visible = False
                Label3.Visible = False
                Explosion.Visible = True
                ButtOpt1.Visible = True
                ButtOpt2.Visible = True
                ButtOpt3.Visible = True
                ButtOpt4.Visible = True
                Question.Visible = False
                'OPT_BOX.Visible = False

                Explosion.Location = New Point(X_sights - 93, 200) 'To make explosion coincide with number shot
                My.Computer.Audio.Play("C:\Documents and Settings\useradmin\My Documents\Visual Studio
2008\Projects\Shoot\Smashing.wav")

            Else
                Trav1.Enabled = False
                Label1.Visible = False
                Label2.Visible = False
                Label3.Visible = False

                My.Computer.Audio.Play("C:\Documents and Settings\useradmin\My Documents\Visual Studio
2008\Projects\Shoot\Computer Error Alert.wav")
                ButtOpt1.Visible = True
                ButtOpt2.Visible = True
                ButtOpt3.Visible = True
                ButtOpt4.Visible = True
                Question.Visible = False
                'OPT_BOX.Visible = False

            End If
        End If

        If act_or_not = 0 Then
            If Question_responseP1 = 1 Then
                Label4.Visible = False
                Label5.Visible = False
                Label6.Visible = False
                Explosion.Visible = True
                ButtOpt1.Visible = True
                ButtOpt2.Visible = True
                ButtOpt3.Visible = True
                ButtOpt4.Visible = True
                Question.Visible = False
                'OPT_BOX.Visible = False
                ' Explosion.Location = New Point(X_sights - 93, 200) 'To make explosion coincide with number shot
```

```
            My.Computer.Audio.Play("C:\Documents and Settings\useradmin\My Documents\Visual Studio 2008\Projects\Shoot\Smashing.wav")

        Else
            My.Computer.Audio.Play("C:\Documents and Settings\useradmin\My Documents\Visual Studio 2008\Projects\Shoot\Computer Error Alert.wav")
            ButtOpt1.Visible = True
            ButtOpt2.Visible = True
            ButtOpt3.Visible = True
            ButtOpt4.Visible = True
            But1_P1.Visible = True
            But1_P2.Visible = True
            But2_P1.Visible = True
            But2_P2.Visible = True
            But3_P1.Visible = True
            But3_P2.Visible = True
            But4_P1.Visible = True
            But4_P2.Visible = True
            Question.Visible = False
            Label4.Visible = False
            Label5.Visible = False
            Label6.Visible = False
            'OPT_BOX.Visible = False

            'Explosion.Visible = False
        End If
    End If

End Sub
```

```
Private Sub ExplodeP2()
    If act_or_not = 1 Then
        If Question_responseP2 = 1 Then
            Trav1.Enabled = False
            Label1.Visible = False
            Label2.Visible = False
            Label3.Visible = False
            Explosion.Visible = True
            ButtOpt1.Visible = True
            ButtOpt2.Visible = True
            ButtOpt3.Visible = True
            ButtOpt4.Visible = True
            Question.Visible = False

            Explosion.Location = New Point(X_sights1 - 93, 200) 'To make explosion coincide with number shot
            My.Computer.Audio.Play("C:\Documents and Settings\useradmin\My Documents\Visual Studio 2008\Projects\Shoot\Smashing.wav")

        Else
            Trav1.Enabled = False
            Label1.Visible = False
            Label2.Visible = False
            Label3.Visible = False

            My.Computer.Audio.Play("C:\Documents and Settings\useradmin\My Documents\Visual Studio 2008\Projects\Shoot\Computer Error Alert.wav")
```

```
            ButtOpt1.Visible = True
            ButtOpt2.Visible = True
            ButtOpt3.Visible = True
            ButtOpt4.Visible = True
            Question.Visible = False

        End If
    End If

    If act_or_not = 0 Then
        If Question_responseP2 = 1 Then
            Label4.Visible = False
            Label5.Visible = False
            Label6.Visible = False
            Explosion.Visible = True
            ButtOpt1.Visible = True
            ButtOpt2.Visible = True
            ButtOpt3.Visible = True
            ButtOpt4.Visible = True
            But1_P1.Visible = True
            But1_P2.Visible = True
            But2_P1.Visible = True
            But2_P2.Visible = True
            But3_P1.Visible = True
            But3_P2.Visible = True
            But4_P1.Visible = True
            But4_P2.Visible = True

            Question.Visible = False
            ' Explosion.Location = New Point(X_sights - 93, 200) 'To make explosion coincide with number shot
            My.Computer.Audio.Play("C:\Documents and Settings\useradmin\My Documents\Visual Studio
2008\Projects\Shoot\Smashing.wav")

        Else
            My.Computer.Audio.Play("C:\Documents and Settings\useradmin\My Documents\Visual Studio
2008\Projects\Shoot\Computer Error Alert.wav")
            ButtOpt1.Visible = True
            ButtOpt2.Visible = True
            ButtOpt3.Visible = True
            ButtOpt4.Visible = True
            Question.Visible = False
            Label4.Visible = False
            Label5.Visible = False
            Label6.Visible = False

            'Explosion.Visible = False
        End If
    End If

End Sub
```

```
Public Sub record_start_of_data_line()
    My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), quest_num & " ", True)
' number of trial
    My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), start_of_trial & " ",
True)
```

```
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), quest & " " &
questions(quest, 5) & " ", True) ' COLUMN 3,4 = question and answer
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), start_of_option & " ",
True)

    End Sub
```

```
    Protected Overrides Function ProcessCmdKey(ByRef msg As System.Windows.Forms.Message, ByVal
keyData As System.Windows.Forms.Keys) As Boolean
        If msg.Msg = 256 Then ' WinMsg was a keypress. should always see this value anyway - note from coder
            If act_or_not = 1 Then
                Select Case keyData ' sets distance to move arrows in the two keyboards (to go right or left) (A - Q
= P1; Q - E = P2)
                    Case Keys.A
                        If X_sights > x_min Then X_sights = X_sights - 10
                        LineShape2.StartPoint = New Point(X_sights, Y_line - 20)
                        LineShape2.EndPoint = New Point(X_sights, Y_line + 20)
                    Case Keys.Q
                        If X_sights1 > x_min Then X_sights1 = X_sights1 - 10
                        LineShape3.StartPoint = New Point(X_sights1, Y_line1 - 20)
                        LineShape3.EndPoint = New Point(X_sights1, Y_line1 + 20)

                    Case Keys.D
                        If X_sights < x_max Then X_sights = X_sights + 10
                        LineShape2.StartPoint = New Point(X_sights, Y_line - 20)
                        LineShape2.EndPoint = New Point(X_sights, Y_line + 20)
                    Case Keys.E
                        If X_sights1 < x_max Then X_sights1 = X_sights1 + 10
                        LineShape3.StartPoint = New Point(X_sights1, Y_line1 - 20)
                        LineShape3.EndPoint = New Point(X_sights1, Y_line1 + 20)


                    Case Keys.L ' sets firing key for P1
                        'If shoot = 0 Then shoot = 1


                        If press_fire = 0 Then 'have you hit a button
                            press_fire = 1
                            shooting.Enabled = True
                            If ((loc_x_1 + box_x / 2 - box_x / 2 < X_sights) And (X_sights < loc_x_1 + box_x / 2 + box_x /
2)) Or ((loc_x_2 + box_x / 2 - box_x / 2 < X_sights) And (X_sights < loc_x_2 + box_x / 2 + box_x / 2)) Or
((loc_x_3 + box_x / 2 - box_x / 2 < X_sights) And (X_sights < loc_x_3 + box_x / 2 + box_x / 2) And (loc_y_3 +
box_y / 2 - box_y / 2 < Y_line)) Or ((loc_x_4 + box_x / 2 - box_x / 2 < X_sights) And (X_sights < loc_x_4 +
box_x / 2 + box_x / 2) And (loc_y_4 + box_y / 2 - box_y / 2 < Y_line)) Then
                                'above is "have you hit a box?


                                'Option 1
                                If ((loc_x_1 + box_x / 2 - box_x / 2 < X_sights) And (X_sights < loc_x_1 + box_x / 2 + box_x
/ 2) And (loc_y_1 + box_y / 2 - box_y / 2 < Y_line) And (Y_line < loc_y_1 + box_y / 2 + box_y / 2)) Then
                                    ' above is "have you hit box 1, etc
                                    Question_responseP1 = 1
                                    mark_hitP1()
                                    ExplodeP1()
                                    ActionFeedbackP1()
                                    'lblMessage.Text = quest & " " & questions(quest, 5)
```

```
                    End If


                    'Option 2
                    If ((loc_x_2 + box_x / 2 - box_x / 2 < X_sights) And (X_sights < loc_x_2 + box_x / 2 + box_x
/ 2) And (loc_y_2 + box_y / 2 - box_y / 2 < Y_line) And (Y_line < loc_y_2 + box_y / 2 + box_y / 2)) Then
                        Question_responseP1 = 2
                        mark_hitP1()
                        ExplodeP1()
                        ActionFeedbackP1()
                        'lblMessage.Text = quest & " " & questions(quest, 5)
                        'WellDone.Visible = True
                        'WellDone.Text = questions(quest, 4 + NAns + Question_response)
                    End If

                    'OPtion 3
                    If ((loc_x_3 + box_x / 2 - box_x / 2 < X_sights) And (X_sights < loc_x_3 + box_x / 2 + box_x
/ 2) And (loc_y_3 + box_y / 2 - box_y / 2 < Y_line) And (Y_line < loc_y_3 + box_y / 2 + box_y / 2)) Then
                        Question_responseP1 = 3
                        mark_hitP1()
                        ExplodeP1()
                        ActionFeedbackP1()
                        'lblMessage.Text = quest & " " & questions(quest, 5)
                        'WellDone.Visible = True
                        'WellDone.Text = questions(quest, 4 + NAns + Question_response)
                    End If

                    'OPtion 4
                    If ((loc_x_4 + box_x / 2 - box_x / 2 < X_sights) And (X_sights < loc_x_4 + box_x / 2 + box_x
/ 2) And (loc_y_4 + box_y / 2 - box_y / 2 < Y_line) And (Y_line < loc_y_4 + box_y / 2 + box_y / 2)) Then
                        Question_responseP1 = 4
                        mark_hitP1()
                        ExplodeP1()
                        ActionFeedbackP1()
                        'lblMessage.Text = quest & " " & questions(quest, 5)
                    End If
                    'Else : lblMessage.Text = "MISS!"
                End If
            End If

        Case Keys.O ' For P2
            'If shoot = 0 Then shoot = 1


            If press_fire = 0 Then
                press_fire = 1
                shooting.Enabled = True
                If ((loc_x_1 + box_x / 2 - box_x / 2 < X_sights1) And (X_sights1 < loc_x_1 + box_x / 2 + box_x
/ 2)) Or ((loc_x_2 + box_x / 2 - box_x / 2 < X_sights1) And (X_sights1 < loc_x_2 + box_x / 2 + box_x / 2)) Or
((loc_x_3 + box_x / 2 - box_x / 2 < X_sights1) And (X_sights1 < loc_x_3 + box_x / 2 + box_x / 2) And (loc_y_3
+ box_y / 2 - box_y / 2 < Y_line1)) Or ((loc_x_4 + box_x / 2 - box_x / 2 < X_sights1) And (X_sights1 < loc_x_4
+ box_x / 2 + box_x / 2) And (loc_y_4 + box_y / 2 - box_y / 2 < Y_line1)) Then

                    'Option 1
```

```
                    If ((loc_x_1 + box_x / 2 - box_x / 2 < X_sights1) And (X_sights1 < loc_x_1 + box_x / 2 +
box_x / 2) And (loc_y_1 + box_y / 2 - box_y / 2 < Y_line1) And (Y_line1 < loc_y_1 + box_y / 2 + box_y / 2))
Then
                        Question_responseP2 = 1
                        mark_hitP2()
                        ExplodeP2()
                        ActionFeedbackP2()
                    End If

                    'Option 2
                    If ((loc_x_2 + box_x / 2 - box_x / 2 < X_sights1) And (X_sights1 < loc_x_2 + box_x / 2 +
box_x / 2) And (loc_y_2 + box_y / 2 - box_y / 2 < Y_line1) And (Y_line1 < loc_y_2 + box_y / 2 + box_y / 2))
Then
                        'lblMessage.Text = "HIT!"
                        Question_responseP2 = 2
                        mark_hitP2()
                        ExplodeP2()
                        ActionFeedbackP2()
                        'WellDone.Visible = True
                        'WellDone.Text = questions(quest, 4 + NAns + Question_response)
                    End If

                    'OPtion 3
                    If ((loc_x_3 + box_x / 2 - box_x / 2 < X_sights1) And (X_sights1 < loc_x_3 + box_x / 2 +
box_x / 2) And (loc_y_3 + box_y / 2 - box_y / 2 < Y_line1) And (Y_line1 < loc_y_3 + box_y / 2 + box_y / 2))
Then
                        'lblMessage.Text = "HIT!"
                        Question_responseP2 = 3
                        mark_hitP2()
                        ExplodeP2()
                        ActionFeedbackP2()
                        'WellDone.Visible = True
                        'WellDone.Text = questions(quest, 4 + NAns + Question_response)
                    End If

                    'OPtion 4
                    If ((loc_x_4 + box_x / 2 - box_x / 2 < X_sights1) And (X_sights1 < loc_x_4 + box_x / 2 +
box_x / 2) And (loc_y_4 + box_y / 2 - box_y / 2 < Y_line1) And (Y_line1 < loc_y_4 + box_y / 2 + box_y / 2))
Then
                        'lblMessage.Text = "HIT!"
                        Question_responseP2 = 4
                        mark_hitP2()
                        ExplodeP2()
                        ActionFeedbackP2()
                    End If
                End If
                'press_fire = 0
            End If

        End Select
    End If

    If act_or_not = 0 Then
        'If shoot = 0 Then shoot = 1
```

```
Select Case keyData ' to highlight boxes as arrow keys are moved in no action
    Case Keys.D 'goes clockwise in P1
        If Keys.D = keyData Then
            rot = rot + 1
            If rot = 5 Then rot = 1
            highlight_boxP1()
        End If
    Case Keys.E 'goes clockwise in P2
        If Keys.E = keyData Then
            rot = rot + 1
            If rot = 5 Then rot = 1
            highlight_boxP2()
        End If
    Case Keys.A 'goes anticlockwise in P1
        If Keys.A = keyData Then
            rot = rot - 1
            If rot = 0 Then rot = 4
            highlight_boxP1()
        End If
    Case Keys.Q 'goes anticlockwise in P2
        If Keys.Q = keyData Then
            rot = rot - 1
            If rot = 0 Then rot = 4
            highlight_boxP2()
        End If

    Case Keys.L ' Fire for P1
        If press_fire = 0 Then
            press_fire = 1

            If Keys.L = keyData Then
                If rot = 1 Then
                    Question_responseP1 = screen_order(1)
                    'lblMessage.Text = quest & " " & questions(quest, 5)
                    'lblMessage.Text = Question_responseP1 & " " & screen_order(1)
                    Explosion.Location = New Point(158 - x_corr, 171 - y_corr)
                End If

                If rot = 2 Then
                    Question_responseP1 = screen_order(2)
                    'lblMessage.Text = quest & " " & questions(quest, 5)
                    'lblMessage.Text = Question_responseP1 & " " & screen_order(2)
                    Explosion.Location = New Point(736 - x_corr, 171 - y_corr)
                End If

                If rot = 3 Then
                    Question_responseP1 = screen_order(4)
                    'lblMessage.Text = quest & " " & questions(quest, 5)
                    'lblMessage.Text = Question_responseP1 & " " & screen_order(4)
                    Explosion.Location = New Point(736 - x_corr, 402 - y_corr)
                End If

                If rot = 4 Then
                    Question_responseP1 = screen_order(3)
                    'lblMessage.Text = quest & " " & questions(quest, 5)
```

```
                'lblMessage.Text = Question_responseP1 & " " & screen_order(3)
                Explosion.Location = New Point(158 - x_corr, 402 - y_corr)
              End If
              mark_hitP1()
              ExplodeP1()
              Feedback_delay.Enabled = True

            End If
          End If

        Case Keys.O ' Fire for P2
          If press_fire = 0 Then
            press_fire = 1

            If Keys.O = keyData Then
              If rot = 1 Then
                Question_responseP2 = screen_order(1)
                'lblMessage.Text = "hello" & screen_order(1)
                Explosion.Location = New Point(158 - x_corr, 171 - y_corr)
              End If
              If rot = 2 Then
                Question_responseP2 = screen_order(2)
                'lblMessage.Text = "hello" & screen_order(2)
                Explosion.Location = New Point(736 - x_corr, 171 - y_corr)
              End If
              If rot = 3 Then
                Question_responseP2 = screen_order(4)
                'lblMessage.Text = "hello" & screen_order(3)
                Explosion.Location = New Point(736 - x_corr, 402 - y_corr)
              End If
              If rot = 4 Then
                Question_responseP2 = screen_order(3)
                'lblMessage.Text = "hello" & screen_order(4)
                Explosion.Location = New Point(158 - x_corr, 402 - y_corr)
              End If
            End If
            'lblMessage.Text = "hello" & screen_order(4) & rot
            mark_hitP2()
            ExplodeP2()
            Feedback_delay.Enabled = True

            'press_fire = 0
            'Return MyBase.ProcessCmdKey(msg, keyData) '- PHJ: not sure if this needed?!
          End If
      End Select
    End If
  End If
End Function
```

```
Private Sub shooting_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
shooting.Tick
    press_fire = 0
    shooting.Enabled = False

End Sub
```

```
    Private Sub cfgbox_TextChanged(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles cfgbox.TextChanged

    End Sub
```

```
    Public Sub set_colourP1()
        Select Case colour_order(1)
            Case 1
                'ButtOpt1.BackColor = Color.Black
                But1_P1.BackColor = Color.Black
            Case 2
                'ButtOpt1.BackColor = Color.Black
                But1_P1.BackColor = Color.Black
            Case 3
                'ButtOpt1.BackColor = Color.Black
                But1_P1.BackColor = Color.Black
            Case 4
                'ButtOpt1.BackColor = Color.Black
                But1_P1.BackColor = Color.Black
        End Select
        Select Case colour_order(2)
            Case 1
                'ButtOpt2.BackColor = Color.Black
                But2_P1.BackColor = Color.Black
            Case 2
                'ButtOpt2.BackColor = Color.Black
                But2_P1.BackColor = Color.Black
            Case 3
                'ButtOpt2.BackColor = Color.Black
                But2_P1.BackColor = Color.Black
            Case 4
                'ButtOpt2.BackColor = Color.Black
                But2_P1.BackColor = Color.Black
        End Select
        Select Case colour_order(3)
            Case 1
                'ButtOpt3.BackColor = Color.Black
                But3_P1.BackColor = Color.Black
            Case 2
                'ButtOpt3.BackColor = Color.Black
                But3_P1.BackColor = Color.Black
            Case 3
                'ButtOpt3.BackColor = Color.Black
                But3_P1.BackColor = Color.Black
            Case 4
                'ButtOpt3.BackColor = Color.Black
                But3_P1.BackColor = Color.Black
        End Select
        Select Case colour_order(4)
            Case 1
                'ButtOpt4.BackColor = Color.Black
                But4_P1.BackColor = Color.Black
            Case 2
                'ButtOpt4.BackColor = Color.Black
                But4_P1.BackColor = Color.Black
            Case 3
```

```
            'ButtOpt4.BackColor = Color.Black
            But4_P1.BackColor = Color.Black
        Case 4
            'ButtOpt4.BackColor = Color.Black
            But4_P1.BackColor = Color.Black
    End Select

End Sub
```

```
Public Sub set_colourP2()
    Select Case colour_order(1)
        Case 1
            'ButtOpt1.BackColor = Color.Black
            But1_P2.BackColor = Color.Black
        Case 2
            'ButtOpt1.BackColor = Color.Black
            But1_P2.BackColor = Color.Black
        Case 3
            'ButtOpt1.BackColor = Color.Black
            But1_P2.BackColor = Color.Black
        Case 4
            'ButtOpt1.BackColor = Color.Black
            But1_P2.BackColor = Color.Black
    End Select
    Select Case colour_order(2)
        Case 1
            'ButtOpt2.BackColor = Color.Black
            But2_P2.BackColor = Color.Black
        Case 2
            'ButtOpt2.BackColor = Color.Black
            But2_P2.BackColor = Color.Black
        Case 3
            'ButtOpt2.BackColor = Color.Black
            But2_P2.BackColor = Color.Black
        Case 4
            'ButtOpt2.BackColor = Color.Black
            But2_P2.BackColor = Color.Black
    End Select
    Select Case colour_order(3)
        Case 1
            'ButtOpt3.BackColor = Color.Black
            But3_P2.BackColor = Color.Black
        Case 2
            'ButtOpt3.BackColor = Color.Black
            But3_P2.BackColor = Color.Black
        Case 3
            'ButtOpt3.BackColor = Color.Black
            But3_P2.BackColor = Color.Black
        Case 4
            'ButtOpt3.BackColor = Color.Black
            But3_P2.BackColor = Color.Black
    End Select
    Select Case colour_order(4)
        Case 1
            'ButtOpt4.BackColor = Color.Black
            But4_P2.BackColor = Color.Black
```

```
            Case 2
                'ButtOpt4.BackColor = Color.Black
                But4_P2.BackColor = Color.Black
            Case 3
                'ButtOpt4.BackColor = Color.Black
                But4_P2.BackColor = Color.Black
            Case 4
                'ButtOpt4.BackColor = Color.Black
                But4_P2.BackColor = Color.Black
        End Select

    End Sub
```

```
    Public Sub highlight_boxP1() ' highlights the static boxes in another colour in order to indicate the one
selected
        set_colourP1()
        Select Case rot
            Case 1
                '   ButtOpt1.BackColor = Color.FromArgb(209, 162, 67)
                But1_P1.BackColor = Color.Yellow
            Case 2
                'ButtOpt2.BackColor = Color.FromArgb(209, 162, 67)
                But2_P1.BackColor = Color.Yellow
            Case 3
                'ButtOpt4.BackColor = Color.FromArgb(209, 162, 67)
                But4_P1.BackColor = Color.Yellow
            Case 4
                'ButtOpt3.BackColor = Color.FromArgb(209, 162, 67)
                But3_P1.BackColor = Color.Yellow

        End Select

    End Sub
```

```
    Public Sub highlight_boxP2() ' highlights the static boxes in another colour in order to indicate the one
selected
        set_colourP2()
        Select Case rot
            Case 1
                'ButtOpt1.BackColor = Color.FromArgb(173, 255, 47)
                But1_P2.BackColor = Color.Aqua
            Case 2
                'ButtOpt2.BackColor = Color.FromArgb(173, 255, 47)
                But2_P2.BackColor = Color.Aqua
            Case 3
                'ButtOpt4.BackColor = Color.FromArgb(173, 255, 47)
                But4_P2.BackColor = Color.Aqua
            Case 4
                'ButtOpt3.BackColor = Color.FromArgb(173, 255, 47)
                But3_P2.BackColor = Color.Aqua

        End Select

    End Sub
```

```
    Private Sub Feedback_delay_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Feedback_delay.Tick
```

```
        Feedback_delay.Enabled = False
        ActionFeedbackP1()
        ActionFeedbackP2()

    End Sub
```

```
    Private Sub Timer1_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Timer1.Tick
        num_ints = Trial_Timer.Interval / Timer1.Interval
        clock.Width = clock.Width + (106 / num_ints)

    End Sub

End Class
```

Appendix XIII. Tester Code

```
Option Strict Off
Option Explicit On
'Module InpOut32_Declarations
'Inp and Out declarations for port I/O using inpout32.dll.
'Public Declare Function Inp Lib "inpout32.dll" Alias "Inp32" (ByVal PortAddress As Short) As Short
'Public Declare Sub Out Lib "inpout32.dll" Alias "Out32" (ByVal PortAddress As Short, ByVal Value As Short)
'End Module
Public Class Form1
    Inherits System.Windows.Forms.Form
    Public Function MyTime() As String
        MyTime = Format(Now, "HH:mm:ss:")
    End Function
    Dim startTime, trialTime, eventTime, totalTime As DateTime
    Dim quest As Integer ' this variable used to step through the questions
    Dim quest_num As Integer ' this is where we are in game - 1 = first question presented, 2 = 2nd etc
    Dim key, candidate, taken As Integer
    Dim Taking_Answers, competitor_taking_answers As Integer ' indicates when answers via keyboard are
acceptable
    Dim Taking_Gaming_Response, Taking_competitor_Gaming_Response As Integer 'indicated when gaming
decisions are acceptable
    Dim Wheel_Outcome, Question_response, Gaming_Response, competitor_gaming_response As Integer
    Dim Player_Turn_Score, Competitor_Turn_Score, Player_Total_Score, Competitor_Total_Score As Integer
    Dim Condition_competitor, Competitor_question_response, wrong_answer As Integer
    Dim numquest, QPS, human, hide, slide As Integer ' this is the total number of questions in the
game,questions per slide, slide number
    Dim cfg_data(200), questions(100, 6), Wheel_Outcomes(200) As String
    Dim points(100) As Integer
    Dim SelectOrder(100), Wheel_pick, collab, gaming, num_ints As Integer
    Dim strcfg, strquest, strwheel, strpoints, emotion, tone As String
    ' Dim ITI_Timer.Interval, Learn_Timer.Interval, Q_Pres_Timer.Interval, Q_Resp_Timer.Interval,
G_Resp_Timer.Interval, Q_FB_Timer.Interval, Game_Wheel_Timer.Interval,
    Dim MyRandom As New Random
    Dim WithEvents Player As System.Windows.Forms.TextBox
    Public Sub form1_loadquest(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
MyBase.Load
        'cfg file:
        '01:home directory for files
        '02:question file name
        '03:learning content directory name
        '04:emotion directory name (with subdirectories normal, glad, joy, despair, anxiety, and speech
subdirectory in each)
        '05:question points file name
        '06:data file name
        '07:number of questions (should correspond with size of 02,03 and 05)
        '08:whether opponent should appear (1 or 0 for yes/no)
        '09:whether gaming should be possible (1 or 0 for yes/no)
        '10:ITI_Timer.Interval = time before the ITI = Gaming Feedback Time
        '11:Learn_Timer.Interval = time before the Learning Content = ITI ENDS - BIOPAC Digital Ch 1 Event
starts = Learning presented
        '12:Q_Pres_Timer.Interval = time before question presented = Learning Content Presentation Time =
Ch1 Event ends = Ch 2 Event starts = question presented
```

```
        '13:Q_Resp_Timer.Interval = time before question response requested = Question Presentation Time =
Ch 2 event ends = Ch 3 starts = decision window, when question response arrives, event 3 ends, Event 4
(quest response) starts)
        '14:G_Resp_Timer.Interval = time before gaming response requested = Question Response Window
time, Ch 4 event (quest response) ends, Ch 5 event starts = gaming response requested, when gaming
response arrives, event 5 ends, Event 6 (gaming response) starts)
        '15:Q_FB_Timer.Interval = time before correct answer is revealed = Gaming Response Window time =
when Ch 6 event ends, Ch 7 event starts = question feedback starts
        '16:Game_Wheel_Timer.Interval = time before gaming wheel appears = Question Feedback Time
        '17:G_FB_Timer.Interval = time before gaming outcome revealed = Time taken by wheel spinning,
event 7 ends, Ch 8 event starts = gaming response given = Ch 8 event (gaming feedback) starts
        '18:QPS = number of questions per slide
        '19:whether a human opponent is present or not (1 human, 0 not human)
        '20: hide = hide until gaming

        WheelBox.Height = 500
        WheelBox.Width = 500

    End Sub
```

```
    Public Sub ArrangeQuestionOrder()
        ' SelectOrder will contain the randomised order of questions presented
        SelectOrder(1) = MyRandom.Next(numquest) + 1
        For N = 2 To numquest
            candidate = MyRandom.Next(numquest) + 1
            taken = 0
            For SO = 1 To N - 1
                If SelectOrder(SO) = candidate Then taken = 1
            Next
            If taken = 0 Then
                SelectOrder(N) = candidate
            Else : N = N - 1
            End If
        Next
    End Sub
```

```
    Public Sub btnNew_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
btnNew.Click

        Dim cfgfile As New System.IO.StreamReader(cfgbox.Text + ".txt")
        Dim lengt, cfg As Integer
        btnNew.BackColor = Color.WhiteSmoke
        quest = 0
        key = 0
        lblMessage.Visible = False
        strcfg = cfgfile.ReadLine()
        Do Until strcfg Is Nothing
            For cfg = 1 To 21 ' 21 because that takes strcfg to nothing
                cfg_data(cfg) = strcfg
                strcfg = cfgfile.ReadLine()
                lengt = Microsoft.VisualBasic.Len(cfg_data(cfg))
                If lengt > 3 Then cfg_data(cfg) = Microsoft.VisualBasic.Right(cfg_data(cfg), lengt - 3)
            Next
        Loop

        cfgfile.Close()
        cfgfile.Dispose()
```

```
        numquest = cfg_data(7)
        collab = cfg_data(8)
        gaming = cfg_data(9)
        ITI_Timer.Interval = Int(cfg_data(10))
        Learn_Timer.Interval = cfg_data(11)
        Q_Pres_Timer.Interval = cfg_data(12)
        Q_Resp_Timer.Interval = cfg_data(13)
        G_Resp_Timer.Interval = cfg_data(14)
        Q_FB_Timer.Interval = cfg_data(15)
        Game_Wheel_Timer.Interval = cfg_data(16)
        G_FB_Timer.Interval = cfg_data(17)
        QPS = cfg_data(18)
        human = cfg_data(19)
        hide = cfg_data(20)

        read_questions()
        ArrangeQuestionOrder()
        quest_num = 0
        read_point_values()
        'load up wheel values and start from some random place in the sequence
        read_wheelvalues()
        Wheel_pick = MyRandom.Next(200)
        Taking_Answers = 0
        Taking_Gaming_Response = 2
        Taking_competitor_Gaming_Response = 2
        Competitor_Total_Score = 0
        Player_Total_Score = 0
        Player_score_display.Text = Player_Total_Score
        Competitor_score_display.Text = Competitor_Total_Score
        vid_image.Enabled = True
        'Out(&HE050S, &H0S) ' all EVENTs at zero
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), vbNewLine & "NEW
PARTICIPANT" & " " & DOB.Text & " " & cfgbox.Text, True)
        startTime = Now
        run_game()
    End Sub
```

```
    Public Sub run_game()
        eventTime = Now ' COLUMN 1 = start of trial
        clock.Width = 10
        If quest_num = numquest Then
            ITI_Timer.Enabled = False
            'Learn_Timer.Enabled = False
            endgame()
        Else
            My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), vbNewLine &
eventTime.Subtract(startTime).TotalSeconds & " ", True)
            emotion = "normal"
            Prepare_for_next_question()
            Condition_competitor = 0
            Learn_Timer.Enabled = True
            quest = SelectOrder(quest_num)
            My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), quest & " " &
questions(quest, 5) & " ", True) ' COLUMN 2,3 = question and answer
            Unmark_correct_answer()
```

```
            clear_all_boxes()
            WheelBox.Visible = False
            GlowButtonsOff()
            WheelBox.SendToBack()
            LearningContent.Visible = True
        End If
    End Sub
```

```
    Protected Overrides Function ProcessCmdKey(ByRef msg As System.Windows.Forms.Message, ByVal
keyData As System.Windows.Forms.Keys) As Boolean
        If (msg.Msg = 256 And Taking_Answers = 1) Then ' WinMsg was a keypress. should always see this value
anyway - note from coder
            Tm1Q_ans.Visible = True
            Select Case keyData
                Case Keys.Q
                    Question_response = 1
                    Tm1Q_ans.BackgroundImage = WindowsApplication1.My.Resources.silv_circle
                    record_question_response()
                Case Keys.W
                    Question_response = 2
                    Tm1Q_ans.BackgroundImage = WindowsApplication1.My.Resources.silv_circle
                    record_question_response()
                Case Keys.O
                    Question_response = 3
                    Tm1Q_ans.BackgroundImage = WindowsApplication1.My.Resources.silv_circle
                    record_question_response()
                Case Keys.P
                    Question_response = 4
                    Tm1Q_ans.BackgroundImage = WindowsApplication1.My.Resources.silv_circle
                    record_question_response()
            End Select

            'If hide = 1 Then Tm1Q_ans.Visible = False

        End If
        If (msg.Msg = 256 And competitor_taking_answers = 1) Then ' WinMsg was a keypress. should always
see this value anyway - note from coder
            Tm2Q_ans.Visible = True
            Select Case keyData
                Case Keys.Q
                    Competitor_question_response = 1
                    Tm2Q_ans.BackgroundImage = WindowsApplication1.My.Resources.silv_circle
                    competitor_record_question_response()
                Case Keys.W
                    Competitor_question_response = 2
                    Tm2Q_ans.BackgroundImage = WindowsApplication1.My.Resources.silv_circle
                    competitor_record_question_response()
                Case Keys.E
                    Competitor_question_response = 3
                    Tm2Q_ans.BackgroundImage = WindowsApplication1.My.Resources.silv_circle
                    competitor_record_question_response()
                Case Keys.R
                    Competitor_question_response = 4
                    Tm2Q_ans.BackgroundImage = WindowsApplication1.My.Resources.silv_circle
                    competitor_record_question_response()
            End Select
```

```
        'If hide = 1 Then Tm2Q_ans.Visible = False
      End If

      If (msg.Msg = 256 And Taking_Gaming_Response = 1 And Question_response > 0 And gaming = 1) Then
' WinMsg was a keypress. should always see this value anyway - note from coder
        Select Case keyData
          Case Keys.U
            lblMessage.Text = "You are gaming"
            Tm1_gaming.FillColor = Color.DeepSkyBlue
            Gaming_Response = 1
            record_gaming_response()
            ' Case Keys.I
            '    lblMessage.Text = "You are NOT gaming"
            '   Gaming_Response = 2
            '  If collab = 1 Then Tm2_gaming.FillColor = Color.DeepSkyBlue
            '  record_gaming_response()
        End Select
      End If
      If (msg.Msg = 256 And Taking_competitor_Gaming_Response = 1 And Competitor_question_response
> 0 And gaming = 1) Then ' WinMsg was a keypress. should always see this value anyway - note from coder
        Select Case keyData
          Case Keys.Q
            lblMessage.Text = "You are gaming"
            Tm2_gaming.FillColor = Color.DeepSkyBlue
            competitor_gaming_response = 1 ' so competitor_gaming_response = 1 means competitor is
gaming, 0 is not.
            record_competitor_gaming_response()
            'Case Keys.W
            '  lblMessage.Text = "You are NOT gaming"
            '  competitor_gaming_response = 2
            'If collab = 1 Then Tm2_gaming.FillColor = Color.DeepSkyBlue
            ' record_competitor_gaming_response()
        End Select
      End If
      ' Return MyBase.ProcessCmdKey(msg, keyData) - PHJ: not sure if this needed?!
    End Function
```

```
    Private Sub ITI_Timer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
ITI_Timer.Tick

      ITI_Timer.Enabled = False
      LearningContent.Image = Nothing
      'Learn_Timer.Enabled = True
      run_game()
    End Sub
```

```
    Private Sub Learn_Timer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Learn_Timer.Tick
      'Dim nums As String
      'eventTime = Now ' COLUMN 4 = Time that learning content is presented
      ' Out(&HE050S, &H1S) ' EVENT 1 Starts
      'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
eventTime.Subtract(startTime).TotalSeconds & " ", True)
      Learn_Timer.Enabled = False
      Q_Pres_Timer.Enabled = True
      'slide = Int((quest + QPS - 1) / QPS)
      'nums = Str(slide)
```

```
        'nums = nums.Replace(" ", "")
        'nums = "1"
        'LearningContent.Image = Image.FromFile(cfg_data(1) + "\" + cfg_data(3) + "\" & nums & ".jpg")
        'LearningContent.SizeMode = PictureBoxSizeMode.StretchImage
        'emotion = "normal"
        'tone = "chat_learning"
        'PlayBackgroundSoundResource()

    End Sub
```

```
    Private Sub Q_Pres_Timer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Q_Pres_Timer.Tick
        eventTime = Now ' COLUMN 5 = Time that question is presented
        'Out(&HE050S, &H2S) ' EVENT 1 ends, 2 Starts
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
eventTime.Subtract(startTime).TotalSeconds & " ", True)
        Q_Pres_Timer.Enabled = False
        Q_Resp_Timer.Enabled = True
        Question.Text = questions(quest, 0) ' + " " + Str(quest)
        Option1.Text = questions(quest, 1)
        Option2.Text = questions(quest, 2)
        Option3.Text = questions(quest, 3)
        Option4.Text = questions(quest, 4)
        'Vid_Box.Image = Image.FromFile(cfg_data(1) + "\" + cfg_data(3) + "\" & quest & ".jpg")
        GameProgress.Text = "Q:" + Str(quest_num)

        LearningContent.Visible = False
        'emotion = "normal"
        'tone = "chat_question"
        'PlayBackgroundSoundResource()
    End Sub
```

```
    Private Sub Q_Resp_Timer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Q_Resp_Timer.Tick
        'eventTime = Now ' COLUMN 6 = Time that question response is requested
        'Out(&HE050S, &H4S) ' EVENT 2 ends, 3 Starts
        'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
eventTime.Subtract(startTime).TotalSeconds & " ", True)
        Q_Resp_Timer.Enabled = False
        G_Resp_Timer.Enabled = True
        Clock_int.Enabled = True
        'glow_butt1.FillColor = Color.Orange
        'Tm1Q.BorderColor = Color.Orange
        'If (collab = 1 Or human = 1) Then Tm2Q.BorderColor = Color.Orange
        'lblMessage.Text = "Please Answer the Q"
        Taking_Answers = 1
        'If human = 1 Then competitor_taking_answers = 1
    End Sub
```

```
    Private Sub G_Resp_Timer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
G_Resp_Timer.Tick
        'eventTime = Now ' COLUMN  8 = Time that gaming response is requested
        'Out(&HE050S, &H10S) ' EVENT 4 ends, 5 Starts
        'If Question_response = 0 Then record_question_response()
        'If Competitor_question_response = 0 Then competitor_record_question_response()
        'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
eventTime.Subtract(startTime).TotalSeconds & " ", True)
        'Tm1Q_ans.Visible = True
```

```vb
        'Tm2Q_ans.Visible = True
        'display_comp_resp()
        'display_resp()
        'competitor_gaming_response = 0
        'Gaming_Response = 0
        If Taking_Answers = 1 Then
            eventTime = Now ' COLUMN  7 = Time that question response is given
            My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "P1 " &
eventTime.Subtract(startTime).TotalSeconds & " ", True)
            Taking_Answers = 0
        End If
        G_Resp_Timer.Enabled = False
        ITI_Timer.Enabled = True
        Taking_Answers = 0
        clear_all_boxes()
        'Q_FB_Timer.Enabled = True
        '  If Question_response = 0 Then Gaming_Response = 2
        ' If Question_response = 0 Then display_comp_resp() ' this happens early if no question response
        'glow_butt1.FillColor = Color.Gray
        'Tm1Q.BorderColor = Color.Transparent
        'Tm2Q.BorderColor = Color.Transparent
        'glow_butt2.FillColor = Color.Orange
        'If gaming = 1 Then Tm1_gaming.BorderColor = Color.Orange
        'If (human = 1 And gaming = 1) Then Tm2_gaming.BorderColor = Color.Orange
        'lblMessage.Text = "Are you gaming?"
        'Taking_Answers = 0
        'competitor_taking_answers = 0
        'If Question_response > 0 Then Taking_Gaming_Response = 1
        'If Competitor_question_response > 0 Then Taking_competitor_Gaming_Response = 1
        'If Question_response = 0 Then
        ' Taking_Gaming_Response = 0
        ' Gaming_Response = 2
        ' If (collab = 1 And gaming = 1) Then Tm2_gaming.FillColor = Color.DeepSkyBlue
        ' End If
        'If Question_response = 0 Then Taking_Gaming_Response = 0
        'If Competitor_question_response = 0 Then Taking_competitor_Gaming_Response = 0

        'If collab = 1 Then
        'Competitor_cognition()
        'display_comp_resp()
        'End If


        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), Question_response & "
", True) ' COLUMN 9 = player question response
        'My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
Competitor_question_response & " ", True) ' COLUMN 10 = competitor question response
    End Sub
```

```vb
    Public Sub Q_FB_Timer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Q_FB_Timer.Tick
        If Gaming_Response = 0 Then
            Gaming_Response = 2
            record_gaming_response()
        End If
        If competitor_gaming_response = 0 Then
```

```
        competitor_gaming_response = 2
        record_competitor_gaming_response()
    End If

    My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), Gaming_Response & "
", True) ' COLUMN 12 = gaming response
    My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
competitor_gaming_response & " ", True) ' COLUMN 12 = gaming response

    eventTime = Now ' COLUMN 13 = Time that feedback is given on which is correct
    'Out(&HE050S, &H40S) ' EVENT 6 ends, 7 Starts
    My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
eventTime.Subtract(startTime).TotalSeconds & " ", True)
    Q_FB_Timer.Enabled = False
    Game_Wheel_Timer.Enabled = True
    Mark_Correct_Answer()

    'If (Gaming_Response = 0 And collab = 1) Then
    ' Gaming_Response = 2
    ' If gaming = 1 Then Tm2_gaming.FillColor = Color.DeepSkyBlue
    ' End If

    'If competitor_gaming_response = 1 Then Tm2_gaming.FillColor = Color.DeepSkyBlue

    If Question_response = questions(quest, 5) Then
        lblMessage.Text = "Correct!"
        Player_Turn_Score = points(quest_num)
        'If (Gaming_Response = 2 Or (Gaming_Response = 0 And collab = 1)) Then
        ' Player_Total_Score = Player_Total_Score + Player_Turn_Score
        ' Player_score_display.Text = Player_Total_Score
        'End If
        If Gaming_Response = 2 Then
            Player_Total_Score = Player_Total_Score + Player_Turn_Score
            Player_score_display.Text = Player_Total_Score
        End If
    Else
        lblMessage.Text = "Incorrect"
        blank_player()
    End If

    If Competitor_question_response = questions(quest, 5) Then
        Competitor_Turn_Score = points(quest_num)
        emotion = "glad"
        tone = "happy"
        PlayBackgroundSoundResource()
        'If (((Gaming_Response = 1 Or gaming = 0) And collab = 1) Or competitor_gaming_response = 1) Then
        ' Competitor_Total_Score = Competitor_Total_Score + Competitor_Turn_Score
        ''   Competitor_score_display.Text = Competitor_Total_Score
        'End If
        If competitor_gaming_response = 2 Then
            Competitor_Total_Score = Competitor_Total_Score + Competitor_Turn_Score
            Competitor_score_display.Text = Competitor_Total_Score
        End If
    Else
        blank_competitor()
```

```
        emotion = "despair"
        tone = "no!"
        PlayBackgroundSoundResource()
        Competitor_Turn_Score = 0
      End If
      If Question_response = 0 Then blank_player()
      If Competitor_question_response = 0 Then blank_competitor()
    End Sub
```

```
    Private Sub Game_Wheel_Timer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Game_Wheel_Timer.Tick
      eventTime = Now ' COLUMN 14 = Time that gaming wheel appears
      'Out(&HE050S, &H80S) ' EVENT 7 ends, 8 Starts
      My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
eventTime.Subtract(startTime).TotalSeconds & " ", True)
      If gaming = 1 Then WheelBox.Visible = True
      If (((Gaming_Response = 1) And (Player_Turn_Score > 0) And gaming = 1) Or ((Gaming_Response = 2)
And (Competitor_Turn_Score > 0) And gaming = 1)) Then
        emotion = "anxiety"
        tone = "suspense"
        PlayBackgroundSoundResource()
      End If

      If gaming = 1 Then Points_available.Text = 2 * points(quest_num)
      If gaming = 1 Then Points_available.ForeColor = Color.Turquoise
      If gaming = 1 Then WheelBox.BringToFront()
      glow_butt3.FillColor = Color.Gray
      glow_butt4.FillColor = Color.Orange
      Game_Wheel_Timer.Enabled = False
      G_FB_Timer.Enabled = True
      Wheel_Outcome = Wheel_Outcomes(Wheel_pick)
      If Wheel_pick < 200 Then Wheel_pick = Wheel_pick + 1 Else Wheel_pick = 1
      Wheel1.Enabled = True
    End Sub
```

```
    Public Sub G_FB_Timer_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
G_FB_Timer.Tick
      eventTime = Now ' COLUMN 15 = time that wheel stops spinning
      'Out(&HE050S, &H0S) ' EVENT 8 ends
      My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"),
eventTime.Subtract(startTime).TotalSeconds & " ", True)
      G_FB_Timer.Enabled = False
      Wheel1.Stop() ' stop the turning wheels or they'll carry on for another 100 ms and override this
outcome
      Wheel2.Stop()
      My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), Wheel_Outcome & " ",
True) ' COLUMN 16 = gaming/wheel outcome
      If (Wheel_Outcome = 0 And gaming = 1) Then
        WheelBox.Image = Image.FromFile(cfg_data(1) + "\" + "Wheel 2.jpg")
        If Gaming_Response = 1 Then
          If (Player_Turn_Score > 0 And gaming = 1) Then
            emotion = "joy"
            tone = "yes!"
            PlayBackgroundSoundResource()
          End If
          Player_Turn_Score = 0
        End If
```

```
        If (competitor_gaming_response = 2 And gaming = 1) Then
            If Competitor_Turn_Score > 0 Then
                emotion = "despair"
                tone = "no!"
                PlayBackgroundSoundResource()
            End If
            Competitor_Turn_Score = 0
        End If
    End If
    If (Wheel_Outcome = 1 And gaming = 1) Then
        WheelBox.Image = Image.FromFile(cfg_data(1) + "\" + "Wheel 1.jpg")
        If (Gaming_Response = 1 And gaming = 1) Then
            Player_Turn_Score = Player_Turn_Score * 2
            Player_Total_Score = Player_Total_Score + Player_Turn_Score
            Player_score_display.Text = Player_Total_Score
            emotion = "despair"
            tone = "no!"
            PlayBackgroundSoundResource()
        End If
    End If
    If (Wheel_Outcome = 1 And gaming = 1) Then
        If competitor_gaming_response = 1 Then
            Competitor_Turn_Score = Competitor_Turn_Score * 2
            Competitor_Total_Score = Competitor_Total_Score + Competitor_Turn_Score
            Competitor_score_display.Text = Competitor_Total_Score
            If Competitor_Turn_Score > 0 Then
                emotion = "joy"
                tone = "yes!"
                PlayBackgroundSoundResource()
            End If
        End If
    End If

    My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), points(quest_num) & "
", True) ' COLUMN 17 = points available
    My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), Player_Turn_Score & "
" & Competitor_Turn_Score & " ", True) ' COLUMN 18,19 = turn scores
    My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), Player_Total_Score & "
" & Competitor_Total_Score & " ", True) ' COLUMN 20,21 = total scores


    'ITI_Timer.Enabled = True
  End Sub
```

```
  Private Sub Wheel1_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Wheel1.Tick
    Wheel1.Enabled = False
    If G_FB_Timer.Enabled = True Then 'i.e if we're still counting down to giving gaming feedback wheel is
still turning
        Wheel2.Enabled = True
    End If
    WheelBox.Image = Image.FromFile(cfg_data(1) + "\" + "Wheel 1.jpg")
    WheelBox.SizeMode = PictureBoxSizeMode.StretchImage
  End Sub
```

```vb
    Private Sub Wheel2_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Wheel2.Tick
        Wheel2.Enabled = False
        If G_FB_Timer.Enabled = True Then 'i.e if we're still counting down to giving gaming feedback wheel is
still turning
            Wheel1.Enabled = True
        End If
        WheelBox.Image = Image.FromFile(cfg_data(1) + "\" + "Wheel 2.jpg")
        WheelBox.SizeMode = PictureBoxSizeMode.StretchImage
    End Sub
```

```vb
    Private Sub clear_all_boxes()
        Question.Text = ""
        Option1.Text = ""
        Option2.Text = ""
        Option3.Text = ""
        Option4.Text = ""
    End Sub
```

```vb
    Public Sub Competitor_cognition()
        Dim noise As Integer
        wrong_answer = Int(questions(quest, 5))
        Do Until wrong_answer <> Int(questions(quest, 5))
            wrong_answer = MyRandom.Next(1, 4)
        Loop
        noise = MyRandom.Next(1, 10) ' introduces a 10% chance it does the opposite
        If (Competitor_Total_Score < Player_Total_Score) Then
            If (noise < 9) Then
                Competitor_question_response = questions(quest, 5)
            Else : Competitor_question_response = wrong_answer
            End If
        End If
        If (Competitor_Total_Score >= Player_Total_Score) Then
            If (noise < 9) Then
                Competitor_question_response = wrong_answer
            Else : Competitor_question_response = questions(quest, 5)
            End If
        End If
    End Sub
```

```vb
    Public Sub display_comp_resp()
        'Competitor_cognition()
        Select Case Competitor_question_response
            Case 1
                Tm2Q_ans.BackgroundImage = WindowsApplication1.My.Resources.red_square2
            Case 2
                Tm2Q_ans.BackgroundImage = WindowsApplication1.My.Resources.yell_circle1
            Case 3
                Tm2Q_ans.BackgroundImage = WindowsApplication1.My.Resources.green_tri
            Case 4
                Tm2Q_ans.BackgroundImage = WindowsApplication1.My.Resources.blue_star
        End Select
        Tm2Q_ans.Visible = True
    End Sub
```

```vb
    Public Sub display_resp()
        'Competitor_cognition()
        Select Case Question_response
            Case 1
```

```
            Tm1Q_ans.BackgroundImage = WindowsApplication1.My.Resources.red_square2
        Case 2
            Tm1Q_ans.BackgroundImage = WindowsApplication1.My.Resources.yell_circle1
        Case 3
            Tm1Q_ans.BackgroundImage = WindowsApplication1.My.Resources.green_tri
        Case 4
            Tm1Q_ans.BackgroundImage = WindowsApplication1.My.Resources.blue_star
    End Select
    Tm1Q_ans.Visible = True
End Sub
```

```
Public Sub Mark_Correct_Answer()
    glow_butt2.FillColor = Color.Gray
    glow_butt3.FillColor = Color.Orange
    Tm1_gaming.BorderColor = Color.Transparent
    Tm2_gaming.BorderColor = Color.Transparent

    Select Case questions(quest, 5)
        Case 1
            tick1.Visible = True
        Case 2
            tick2.Visible = True
        Case 3
            tick3.Visible = True
        Case 4
            tick4.Visible = True
    End Select
End Sub
```

```
Public Sub Unmark_correct_answer()
    tick1.Visible = False
    tick2.Visible = False
    tick3.Visible = False
    tick4.Visible = False
End Sub
```

```
Public Sub GlowButtonsOff()
    glow_butt1.FillColor = Color.Gray
    glow_butt2.FillColor = Color.Gray
    glow_butt3.FillColor = Color.Gray
    glow_butt4.FillColor = Color.Gray
    Tm1Q.BorderColor = Color.Transparent
    Tm2Q.BorderColor = Color.Transparent
    Tm1_gaming.BorderColor = Color.Transparent
    Tm2_gaming.BorderColor = Color.Transparent
End Sub
```

```
Public Sub blank_player()
    Tm1Q_ans.Visible = False
    RectangleShape2.FillColor = Color.Black
    Tm1_gaming.FillColor = Color.Transparent
    TextBox1.BackColor = Color.Black
    TextBox1.ForeColor = Color.DarkGray
    Player_score_display.BackColor = Color.Black
    Player_score_display.ForeColor = Color.DarkGray
End Sub
```

```
Public Sub blank_competitor()
    Tm2Q_ans.Visible = False
```

```vb
        RectangleShape3.FillColor = Color.Black
        Tm2_gaming.FillColor = Color.Transparent
        TextBox2.BackColor = Color.Black
        TextBox2.ForeColor = Color.DarkGray
        Competitor_score_display.BackColor = Color.Black
        Competitor_score_display.ForeColor = Color.DarkGray
    End Sub
```

```vb
    Public Sub Prepare_for_next_question()
        quest_num = quest_num + 1
        Points_available.Text = points(quest_num)
        Points_available.ForeColor = Color.White
        Tm1Q_ans.BackgroundImage = WindowsApplication1.My.Resources.black
        Tm2Q_ans.BackgroundImage = WindowsApplication1.My.Resources.black
        Gaming_Response = 0
        competitor_gaming_response = 0
        Question_response = 0
        Competitor_question_response = 0
        Taking_Gaming_Response = 2
        Taking_competitor_Gaming_Response = 2
        Taking_Answers = 0
        Competitor_Turn_Score = 0
        Player_Turn_Score = 0
        Tm1Q_ans.Visible = False
        Tm2Q_ans.Visible = False
        TextBox1.ForeColor = Color.White
        TextBox2.ForeColor = Color.White
        TextBox2.BackColor = Color.Gray
        TextBox1.BackColor = Color.Gray
        RectangleShape2.FillColor = Color.Gray
        RectangleShape3.FillColor = Color.Gray
        Tm1_gaming.FillColor = Color.Black
        Tm2_gaming.FillColor = Color.Black
        Competitor_score_display.BackColor = Color.Gray
        Competitor_score_display.ForeColor = Color.White
        Player_score_display.BackColor = Color.Gray
        Player_score_display.ForeColor = Color.White
        If (collab = 0 And human = 0) Then
            blank_competitor()
            TextBox2.Visible = False
            Competitor_score_display.Visible = False
        End If
    End Sub
```

```vb
    Private Sub Stop_Button_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Stop_Button.Click
        Me.Close()
    End Sub
```

```vb
    Private Sub vid_image_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
vid_image.Tick
        If collab = 1 Then Vid_Box.Image = Image.FromFile(cfg_data(1) + "\" + cfg_data(4) + "\" + emotion +
"\Picture 00" & (1 + MyRandom.Next(5)) & ".jpg")
    End Sub
```

```vb
    Sub PlayBackgroundSoundResource()
        If collab = 1 Then My.Computer.Audio.Play((cfg_data(1) + "\" + cfg_data(4) + "\speech\" + tone + "\" &
(1 + MyRandom.Next(10)) & ".wav"), AudioPlayMode.Background)
```

```
    End Sub
    Public Sub record_question_response()
        eventTime = Now ' COLUMN  7 = Time that question response is given
        '  Out(&HE050S, &H8S) ' EVENT 3 ends continues, 4 Starts
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "P1 " &
eventTime.Subtract(startTime).TotalSeconds & " ", True)
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), Question_response & "
", True) ' COLUMN 9 = player question response
        Taking_Answers = 0
        clear_all_boxes()
        ITI_Timer.Enabled = True
        G_Resp_Timer.Enabled = False
    End Sub
    Public Sub competitor_record_question_response()
        eventTime = Now ' COLUMN  7 = Time that question response is given
        'Out(&HE050S, &H8S) ' EVENT 3 ends continues, 4 Starts
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "P2 " &
eventTime.Subtract(startTime).TotalSeconds & " ", True)
        competitor_taking_answers = 0
    End Sub
    Public Sub record_gaming_response()
        eventTime = Now ' COLUMN  11 = Time that gaming response is given
        'Out(&HE050S, &H20S) ' EVENT 5 ends continues, 6 Starts
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "P1g " &
eventTime.Subtract(startTime).TotalSeconds & " ", True)
        Taking_Gaming_Response = 0
    End Sub
    Public Sub record_competitor_gaming_response()
        eventTime = Now ' COLUMN  11 = Time that gaming response is given
        'Out(&HE050S, &H20S) ' EVENT 5 ends continues, 6 Starts
        My.Computer.FileSystem.WriteAllText((cfg_data(1) + "\" + cfg_data(6) + ".txt"), "P2g " &
eventTime.Subtract(startTime).TotalSeconds & " ", True)
        Taking_competitor_Gaming_Response = 0
    End Sub
    Public Sub read_questions()
        Dim objfile As New System.IO.StreamReader(cfg_data(1) + "\" + cfg_data(2) + ".txt")
        'Dim objfile As New System.IO.StreamReader("C:\Documents and Settings\edpahj\My
Documents\ZR\z_questions.txt")
        strquest = objfile.ReadLine()
        Do Until strquest Is Nothing
            quest = quest + 1
            For N = 0 To 5
                questions(quest, N) = strquest
                strquest = objfile.ReadLine()
            Next
        Loop
        ' lblMessage.Text=questions(
        objfile.Close()
        objfile.Dispose()
    End Sub
    Public Sub read_wheelvalues()
        Dim wheelfile As New System.IO.StreamReader(cfg_data(1) + "\" + "wheel.txt")
        strwheel = wheelfile.ReadLine()
        Do Until strwheel Is Nothing
```

```
            For N = 1 To 200
                Wheel_Outcomes(N) = strwheel
                strwheel = wheelfile.ReadLine()
            Next
        Loop
        wheelfile.Close()
        wheelfile.Dispose()
    End Sub
```

```
    Public Sub read_point_values()
        Dim pointfile As New System.IO.StreamReader(cfg_data(1) + "\" + cfg_data(5) + ".txt")
        strpoints = pointfile.ReadLine()
        Do Until strpoints Is Nothing
            For N = 1 To numquest
                points(N) = strpoints
                strpoints = pointfile.ReadLine()
            Next
        Loop
        pointfile.Close()
        pointfile.Dispose()
    End Sub
```

```
    Public Sub endgame()
        WheelBox.SendToBack()
        btnNew.BackColor = Color.Red
        clear_all_boxes()
        Unmark_correct_answer()
        GlowButtonsOff()
        If (Player_Total_Score < Competitor_Total_Score) Then
            Question.Text = "GAME OVER - winner is Player B!"
            emotion = "joy"
            tone = "won"
            PlayBackgroundSoundResource()
        End If

        If (Player_Total_Score > Competitor_Total_Score) Then
            Question.Text = "GAME OVER - winner is Player A!"
            emotion = "sad"
            tone = "lost"
            PlayBackgroundSoundResource()
        End If

        If (Player_Total_Score = Competitor_Total_Score And collab = 1) Then Question.Text = "GAME OVER -
it's a draw!"
        WheelBox.SendToBack()
        clear_all_boxes()
        Player_score_display.BackColor = Color.Red
        Competitor_score_display.BackColor = Color.Red
        lblMessage.Visible = True
        clock.Visible = False
        lblMessage.Text = "THANK YOU"
        'System.Threading.Thread.Sleep(8000)
        'Me.Close()
    End Sub
```

```
    Private Sub WheelBox_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
WheelBox.Click
```

```
    End Sub
    Private Sub Clock_int_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Clock_int.Tick
        num_ints = G_Resp_Timer.Interval / Clock_int.Interval
        If clock.Width < 244 Then clock.Width = clock.Width + (244 / num_ints)
    End Sub
End Class
```